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Yukinobu Kitamura

Quest for Good Money

Past, Present and Future

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Preface

The purpose of this book is to put the recent development of money into perspective. Fortunately, I have witnessed all the challenges and efforts from within one of the major central banks in the world, the Bank of Japan, during the past 30 years from 1991 to 2021. Sometimes I was involved in research projects concerning money and the digital economy at the Bank. Sometimes I was invited to participate in research programs at the Japanese Bankers Association. Sometimes I independently conducted my research out of my own curiosity, and this book reflects the history of my own research since the 1990s.

The organization of the book is very simple: I have put the chapters in the chronological order of my research history except for Chap. 1. I have not updated the data, statistics, and references. I present here the chapters as they were originally written with information I had at hand at the time. First publications and presentations of original works based on each chapter are as follows. Chapter 1, "Overview of the History of Money", is based on my public lecture on June 21, 2017, at the 94th Hitotsubashi Forum 21 on Money (in Japanese). Chapter 2, "On the Choice of Optimal Currency Denominations", is based on my paper published in *Monetary and Economic Studies*, 8(5), 237–247 (1999, 12), Bank of Japan (in Japanese). Chapter 3, "The Impact of Denomination Choice on Commercial Trading: A Policy Evaluation of a New Iraqi Monetary System", was presented at academic conferences and seminars. A mimeograph version became available on August 25, 2004 (in Japanese). Chapter 4, "Diffusion of Electronic Money and Choice of Payment Methods", was published in the report of the Financial Services Research Association in June 2005 (in Japanese). Chapter 5, "The Impact of Electronic Money on Demand for Cash: Time Series Analysis", was published in *Financial Review,* 97(5) (2009, 12), 129–152, Ministry of Finance, jointly written with Mahito Omori and Kenta Nishida (in Japanese). Chapter 6, "Can We Stabilize the Price of a Cryptocurrency? Understanding the Design of Bitcoin and Its Potential to Compete with Central Bank Money", was published in the *Hitotsubashi Journal of Economics*, 60(1), 41–60 (in English)(2016, 6), jointly written with Mitsuru Iwamura, Tsutomu Matsumoto, and Kenji Saito. Chapter 7, "Cashless Society: Facts and Issues", was published in the report of the Financial Services Research Association in April 2018 (in Japanese).

Chapter 8, “The Future of Money or Quest for Good Money”, was originally and specifically written for this book.

My first memory of coins and bank notes goes back to the summer of 1966 when my father, Tetsuro Kitamura, came back from the United States and Canada after serving as Chief Curator for the Japanese art exhibition touring major US cities, including Los Angeles, Detroit, and Philadelphia, as well as the Canadian province of Ontario, Canada, in 1965–1966. I was a local primary school pupil in Kyoto, aged 10. My father gave me a 1922 silver one-dollar coin, known as a Peace Dollar, as one of his souvenirs for me. He explained to me that this coin was given by the father of a young lady who was a staff member at the Philadelphia Museum of Art. Her name was Riva Lee Asbell and her father, Nathan Asbell, MD, was a well-known physician in Camden, New Jersey. Of course, a 10-year-old boy did not understand anything about coinage and the meaning of the Peace Dollar from the Philadelphia Mint. Somehow, I decided to keep it as my first treasure. My father and I started collecting foreign coins and bank notes, ancient coins and notes, and government bonds whenever we had a chance to obtain them. Now, I have a glass jar of my collection of coins and notes on the front of my desk. Dr. Asbell’s silver dollar is still shining in the jar and inspiring me.

My second encounter with coins and bank notes was when I joined the Bank of Japan in September 1991 as a research economist. I had no idea how the central bank operated and how decisions about monetary policy and daily operations were made. The Bank of Japan gave me very generous opportunities to learn various aspects of the operations of central banking, including bank note issuance and measures against counterfeiting. I eventually started writing on denomination issues, as I explained above. My quest for good money also started.

The title of this book, *Quest for Good Money*, was inspired by Friedrich Hayek’s remark in an interview with Axel Leijonhufvud in 1978, when Hayek was then 79: “I still hope to do a systematic book which I shall call *Good Money*. Beginning really with what would be good money—what do we really want money to be—and then going on to the question of how far would the competitive issue of money provide good money in terms of that standard”. Hayek did not write his book *Good Money*, but it is certain that throughout his life he struggled to find an answer to the question of what would be good money.

We usually do not describe money as “good” or “bad”. Needless to say, good or bad is a value judgment. We take money as being neutral or we take money for granted. From my interpretation of Hayek’s words, “good” is neither perfect, nor the best, nor the most efficient, nor optimal. We require future money to be simply good enough for our daily use. In other words, money must function reasonably well and be convenient for our ever-changing lifestyle.

In addition, George Selgin’s *Good Money: Birmingham Button Makers, the Royal Mint, and the Beginning of Modern Coinage 1775–1821*, University of Michigan Press (2008), is another inspiration. This book discusses how the private button maker became the Royal mint under the British Industrial Revolution. The story suggests a private manufacturing company can make better money than the traditional old-fashioned mints. The future of money must be created jointly with both the private sector and the central banking community. Anyone with good skill and a good idea can participate in formulating and designing good money.

Tokyo, Japan Yukinobu Kitamura

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Tokyo, Japan Yukinobu Kitamura

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About the Author

Yukinobu Kitamura After studying at Keio University (B.A. in Economics, 1981) and at the University of Pennsylvania (M.A. in International Relations, 1982), Yukinobu Kitamura specialized in household saving and bequest behavior for his D.Phil. in Economics at the University of Oxford (1989). He then became a Research Assistant at the Institute of Economics and Statistics, University of Oxford (1987–1988) and an Economist at the Organization for Economic Cooperation and Development (OECD) (1988–1991) and at the Bank of Japan (1991–2021). He joined academia as a Guest Associate Professor at Keio University in 1996 and Associate Professor of Economics at Hitotsubashi University in 1999. Since 2002, he has been a Professor of Economics at Hitotsubashi University and Visiting Professor at Keio University. He was the Chair of the Government of Japan's Statistics Committee (2019–2021). He was also a member of the Science Council of Japan (2014–2020) and Chair of the Economic Committee of the Science Council (2017–2020). He is currently a Professor and the Dean of Faculty of Data Science, Rissho University. His research focuses on empirical studies of the Japanese economy and household behavior, including public finance, monetary and fiscal policy and macroeconomics and applied econometrics. He has contributed substantially to the government and Bank of Japan's policy-making.

Chapter 1
Overview of the History of Money

> Money is the solution and all doors that are closed to the man of lesser wealth open to him whom Plutus favors. The invention of this means, which does not have (or at least should not have) any use other than that of serving merely as a means for the exchange of human beings' industry, and with it, however, everything that is also physically good among them, has, especially after it was represented by metal, brought forth a mania for possession which finally, even without enjoyment in the mere possession, and even with the renunciation (of the miser) of making any use of it, contains a power that people believe satisfactorily replaces the lack of every other power. This passion is, if not always morally reprehensible, completely banal, is cultivated merely mechanically, and is attached especially to old people (as a substitute for their natural incapacity). On account of the great influence of this universal means of exchange it has also secured the name of a *faculty* purely and simply, and it is a passion such that, once it has set in, no modification is possible. And if the first of the three passions makes one *hated*, the second makes one *feared*, and the third makes one *despised*.
> Kant (1798) *Anthropology from a Pragmatic Point of View*, English translation version, Cambridge University Press, 2006, p. 174.

1.1 Introduction

The purpose of this chapter is to identify remaining research interests in money in the age of digitalization and put my past research topics in perspective. I have no intention to conduct a comprehensive review of the history of money,[1] nor to search for the origin of money.

[1] Those who want to know the history of money in general, read Angell (1930), Davis (2002), Ingham (2004), Lannoye (2015), Vilar (1969), Desan (2014), Martin (2014), Orrell (2020), and Sehgal (2015), among others. Those who want to learn about ancient money, read Bitros et al. (2021), Harris (2008), Reden (2010) and Seaford (2004). Those who want to learn the origin of money, read Grierson (1977) and Karimzadi (2013). Those who want to learn the current state and future of money, read Allen et al. (2019), Birch (2014, 2019), Coggan (2012), Greco, Jr. (2001), Lietaer and Dunne (2013), Vigna and Casey (2015), among others.

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In my research, I started the choice of optimal currency denomination in 1996. Until then, I had no idea how the currency denomination was determined on what conditions. I was inspired by Telser (1995). I thought about the shortage of small change issues in developing countries in general and in Iraq in particular. It is easy to imagine how difficult it is to price goods and services when a proper set of currency denominations is not available. These research results were eventually realized in the new issuance of the 2000 yen note in the year 2000. I was very pleased to see my first research contribution to the Japanese economy.

Because of the tradition of Marxist economics education in Japan, many Japanese economists once learned the commodity theory of money. Many of them contributed in the literature. But I felt somewhat uncomfortable with this theory and found the credit theory of money more convincing. The recent anthropological discoveries seem to support the credit theory of money.

I then investigated Kant's view of money. Kant was the most important philosopher since Aristotle. Aristotle introduced the commodity theory of money and Thomas Aquinas, Adam Smith, Karl Marx, and Carl Menger, among others, follow this theory. I was curious how Kant thought about the origin and function of money. I had not read Kant's view of money before, so I decided to introduce Kant's writing in this chapter.

John Law's life is very interesting and dramatic as the plays and novels based on his life were actually written by many writers. Law was known to introduce fiat money for the first time on a nation-wide level; nowadays fiat money is common around the world.

My research on money shifted to consider the role of electronic money and its substitution with small denomination coins in the 2000s. Then Bitcoin emerged in the market in 2009. I started to investigate the nature and possibility of cryptocurrency.

In case of the pure exchange economy, it was well known that to achieve a general equilibrium, money has no role. Meanwhile, Samuelson's overlapping generations model found the credit theory of money reasonable and efficient to allocate scarce resources among society over time.

I hope my review of the history of money would help in understanding my research following this chapter.

1.1.1 Two Theories of Money

Broadly speaking, there are two theories of money: the commodity theory of money and the credit theory of money. Imagine there is no money, people have to barter goods with each other and barter only works when there is a *double coincidence of wants*. But such coincidences are likely to be uncommon, as a barter economy seems inefficient. It is said that at some point, people realized that they could trade more easily if they used some intermediate goods or money. According to Orrell (2020), "[A]nthropologists can produce numerous examples of so-called primitive currencies that were based on commodities. Cacao beans in ancient Mexico; cowrie shells in ancient China; tools, iron rings, or brass rods in parts of Africa; human skulls in Sumatra; or woodpecker scalps among the Karok people of the California interior. Feathers in the Solomon Islands. Dog teeth in Papua New Guinea, and whale teeth in Fiji. Strings of wampum beads in the American colonies. Extremely large and heavy stone discs in the Pacific island of Yap" (p. 16).

The commodity theory of money can be traced back to Aristotle (*Politics*, 1255b–1256b). He argues the reason for the birth of metal money as follows: "The reason for this institution of a currency was that all the naturally necessary commodities were not easily portable; and men therefore agreed, for the purpose of their exchanges, to give and receive some commodity (i.e., some form of more or less precious metal) which itself belonged to the category of useful things and possessed the advantage of being easily handled for the purpose of getting the necessities of life. Such commodities were iron, silver, and other similar metals. At first their value was simply determined by their size and weight; but finally a stamp was imposed on the metal which, serving as a definite indication of the quantity, would save men the trouble of determining the value on each occasion" (Aristotle, *Politics*, Vol. 1, Chapter 9, 1257a § 8, p. 24).

Smith (1776) follows Aristotle, and he discusses the origin and use of money as follows: "When the division of labour has been once thoroughly established, it is but a very small part of a man's wants which the produce of his own labour can supply. He supplies the far greater part of them by exchanging that surplus part of the produce of his own labour, which is over and above his own consumption, for such parts of the produce of other men's labour as he has occasion for. Every man thus lives by exchanging, or becomes in some measure a merchant, and the society itself, grows to be what is properly a commercial society." (Chap. 4, p. 22).

Smith goes on discussing, "In all countries, however, men seem at last to have been determined by irresistible reasons to give the preference, for this employment, to metals above every other commodity. Metals can not only be kept with as little loss as any other commodity, scarce anything being less perishable than they are, but they can likewise, without any loss, be divided into any number of parts, as by fusion those parts can easily be reunited again; a quality which no other equally durable commodities possess, and which more than any other quality renders them fit to be the instruments of commerce and circulation." (Chap. 4, pp. 23–24).

Neither Aristotle nor Smith discussed in detail how normal commodities were converted into precious metals under whose initiatives. According to the anthropological evidences of commodity money such as cacao beans, cowrie shells, tools, iron rings and brass rods—these were not used the same way as money. They were used for more ceremonial purposes than means of daily exchange. In addition, as many economists have described, the barter exchanges of, for example, textiles and coffee, coffee and tea, tea and chicken, chicken and fish, and fish and textiles. What we need in such cases is the amount of money suitable for daily shopping, say, 10–50 dollar notes, while the values of metal money minted in ancient times were worth one month's living expenses or more—5,000–10,000 dollars. There was a big gap between money we needed for shopping and metal money we had in the past.[2]

To fill this gap, an alternative theory of money was presented by Innes (1914) and Macleod (1882), among others. That was the credit theory of money. In this theory, money is a social construction in general and a credit relationship in particular. In other words, it is a promise from someone to grant (or repay) a favor (product or service) to the holder of the token. In order to function as money, two further features are crucial; (1) the promise is sufficiently credible, that is, the issues is "creditworthy", and (2) the credit is transferable, that is, also others will accept it as payment for trade.[3] Historically these promises were made by the ruler/king/state for military or civil services or goods and services provided by the merchants.

According to Orrell (2020, pp. 18), well before metallic money was introduced, the Sumerians invented writing, arithmetic, the 24-h day, wheeled vehicles, beer, and the whole concept of urban living. The cities were ruled by temple bureaucrats, who allocated provisions and tracked commercial transactions on clay tablets in what known to historians and museum visitors as cuneiform writing.

It is important to note that temple accountants indicated weights using a system of units that, like their number system, was based on multiples of 60 and that around 3000 BC they began to use a shekel of silver, which is equivalent to around 8.3 g, or about what is in a solid silver ring, as a unit of currency and that the price of everything else was set by the state in terms of these shekels.[4] The Laws of Eshnunna, named after a city near what is now Baghdad, specified prices for various commodities, where volume was measured in units of *sila* that corresponded to about a litre. It was recorded that a month's basic labour was worth 1 shekel of silver,[5] While price lists were set in shekels, this did not actually mean that people bought things in shekels of silver. Instead, the shekels were better seen as a unit of accounting in what amounted to a credit system.[6] Loans attracted interest as a rate known as the *máš,* which meant

[2] Introduction of small-denomination metal money started in medieval times where and when commercial activities such as regular market trading took place. Somewhat related issues are discussed in Chaps. 2 and 3. Commodity money such as cowrie shells may be used as a substitute for small change (denomination).

[3] According to the Stanford Encyclopedia of Philosophy, Philosophy of Money and Finance, Nov. 14, 2018 version.

[4] It is known that the actual silver was located in closely guarded vaults in the temple, the ancient time's equivalent of Fort Knox.

[5] This is a clear evidence that the value of money is set equal to a month's labour, which is the basis of labour theory of value. Kant took this view. We will come back to this later.

[6] Orrell (2020, p. 20) states that "for example, a farmer's use of wool or beer could be paid for at harvest time by delivery of the corresponding quantity of barley, as calculated using official prices. Larger debts were placed inside clay envelopes and marked with the seal of the borrower. The creditor would keep the envelope, and break it open when the debt was repaid, thus cancelling the debt. In some cases, the tablet promised to repay whoever held the envelope, which meant that the right to collect debt could be sold to another person. As we will see, many forms of money start off as debts in exactly this way". This story exactly describes the credit theory of money.

"baby calf", money procreated just like farm animals.[7] For commercial loans the basic rate was set at 1/60 per month (i.e., 1.67%), or 20% a year, which is based on the number system of 60.[8]

As we have seen in Babylonia (Mesopotamia), the Sumerians had developed a functioning financial system that involved money, debt, taxes, legal penalties and so on; discovered many facts about mathematics, astronomy, chemistry, physics, and biology; defined measurements (length, weight, volume, time, a calendar); a unit of accounting; lists of relative prices of commodities, services, and penalties. We need to have a good understanding of money in Babylonia as a financial instrument or a device of credit and accounting.

I will come back to the issues related to the Iraqi monetary system in Chap. 3. It may not be coincidence that I have been fascinated with the monetary and economic systems in Babylonia (Mesopotamia) in ancient time and Iraq and Iran in modern times.

The first known coins date back to the seventh century BC in the kingdom of Lydia (now in Turkey). The coins were oval pieces of a gold–silver alloy called electrum. It could be accurately weighed and measured, and was certified with a stamp, meaning that it would always be accepted within a certain region. One starter (a translation of "shekel") weighed about 14 g and would be equal to, as noted above, one month's basic salary. As the Lydians were active traders, the idea of coinage spread to the Greek cities and surrounding islands. By 600 BC, most Greek city-states issued their own coins. Orrell (2020, p. 22) pointed out that "this hints at the real purpose of coin money, which is that it had less to do with the needs of everyday life, than with the needs of the state. …. By far the largest expense for states at the time was paying and supplying the army, and coins were a neat way of addressing a number of logistical issues". It seems evident that the state created coin money to finance the wars and that the state required payment of taxes in coins, so that the state could maintain the army.

Another example of credit theory of money came from the Pacific Island of Yap. William Henry Furness III, a young anthropologist from the USA, made a two-month vist to Yap and published a broad survey of its physical and social make-up (Furness, 1910). In his book, he mentioned that Yap had a highly developed system of money. It was impossible for Furness not to notice it the moment that he set foot on the island, because its coinage was extremely unusual. It consisted of *fei*—"large, solid, thick stone wheels ranging in diameter from a foot to twelve feet, having in the centre a hole varying in size with diameter of the stone, wherein a pole may be inserted sufficiently large and strong to bear the weight and facilitate transportation" (p. 93). Furness further wrote that "the noteworthy feature of this stone currency is that it is not necessary for its owner to reduce it to possession. After concluding a bargain

7 In Babylonia, interest was taken for granted, given the economy was growing. See Sect. 1.5 of this chapter for and against interest.

8 This is based on the solar calendar, in which the earth goes around the sun. If this orbit is an exact circle, 360 degrees are needed to return to the same position; 60 is equivalent to two months' movement of the earth.

which involves the price of a *fei* too large to be conveniently moved, its new owner is quite content to accept the bare acknowledgement of ownership and without so much as a mark to indicate the exchange, the coin remains undisturbed on the former owner's premises" (p. 96),[9]

John Maynard Keynes was fascinated with this discovery and wrote in a book review, "It has brought us into contact with a people whose ideas on currency are probably more truly philosophical than those of any other country. Modern practice in regard to gold reserves has a good deal to learn from the more logical practice of the island of Yap" (Keynes, 1915).

Martin (2014) eloquently argues that "The story of Yap stripped away a central, misleading preconception about the nature of money that had bedevilled economists for centuries: that what was essential was the currency, the commodity coinage, which functioned as a 'medium of exchange'. It showed that in a primitive economy like Yap, just as in today's system, currency is ephemeral and cosmetic: it is the underlying mechanism of credit accounts and clearing that is the essence of money. … At the centre of this alternative view of money is credit. Money is not a commodity medium of exchange, but a social technology composed of three fundamental elements. The first is an abstract unit of value in which money is denominated. The second is a system of accounts, which keeps track of the individuals' or the institutions' credit or debt balances as they engage in trade with one another. The third is the possibility that the original creditor in a relationship can transfer their debtor's obligation to a third party in settlement of some unrelated debt" (p. 26). The third element is enforced by Macleod's (1882) statement that "these simple considerations at once shew the fundamental nature of a currency. It is quite clear that its primary use is to measure and record debts, and to facilitate their transfer from one person to another; and whatever means be adopted for this purpose, whether it be gold, silver, paper, or anything else, is a currency. We may therefore lay down our fundamental conception that currency and transferable debt are convertible terms; whatever material the currency may consist of, it represents transferable debt, and nothing else" (p. 188).

As we have seen, the value of ancient metal money was about equal to one month's labour. What does it mean? It is almost self-explanatory that the ruler (e.g., king) issued metal money in exchange of one month's labour or military service. The ruler also asked merchants and citizens to accept this metal money in exchange for goods and services that soldiers or servants demanded.

[9] The reason *fei* was not physically exchanged might be that *fei* itself served as a public ledger so that everyone in the island knew and monitored who owned individual *fei* at any moment. It is like the blockchain in the Bitcoin system.

1.2 Kant's View on Money

When we think about money, we rarely encounter Immanuel Kant's view on money. If we face the ethical problem or theory of justice, then ethical and political writings of Kant are indispensable for all researchers in the field, as repeatedly quoted by eminent thinkers in our time such as Berlin, Rawls, and Sen. We are influenced and instructed by Kant to a large extent.

I had a chance to read Kant's writing on money. I was impressed by his writing, so I would like to introduce it here.

Kant wrote about money in two books. One comes is *Anthropology from a Pragmatic Point of View,* which I quote at the beginning of this chapter. The other is *The Metaphysics of Morals*, Part I (I), *Private Right*. We will look at the latter materials closely.

Kant saw various aspects of money:

(1) Money is a thing that can be used only by being *alienated*. Two implications are derived: first, that the alienation of money in exchange is intended not as a gift but for reciprocal acquisition (by a *pactum onerosum*); and second, that money represents all goods, since it is conceived as a universally accepted mere means of commerce (within a nation), having no value in itself, as opposed to things that are *goods* (i.e., that have value in themselves and are related to the particular needs of one or another in the nation) (Kant, 2017, p. 75).

(2) A preliminary real definition of money can be given: it is the universal means by which human beings exchange their industriousness with one another. Thus a nation's wealth, insofar as it is acquired by means of money, is really only the sum of the industry with which human beings pay one another and which is represented by the money in circulation within it (Kant, 2017, p. 76),

(3) How is it possible that what were at first only goods finally became money? This would happen if a powerful, opulent ruler[10] who at first used a material for the adornment and splendour of his attendants (his court) came to levy taxes on his subjects in this material (as goods) (e.g., gold, silver, copper, or a kind of beautiful seashell, cowries; or as in the Congo, a kind of matting called *makutes*; in Senegal, iron ingots,; or on the Coast of Guinea, even black slaves), and in turn paid with this same material, those his demand moved to industry in procuring it, in accordance with exchange regulations with them and among them (on a market or exchange). In this way only (so it seems to me) could a certain merchandise have become a lawful means of exchange of the industry of subjects with one another, and thereby also become the wealth of the nation, that is, *money*. (Kant, 2017, pp. 76–77).

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[10] Kant's view of the creation of money by the ruler was an ancestor of Knapp (1924) *The State Theory of Money*. This is also known as *chartalism* in which the value of currency is based on the power of the issuing government authority as opposed to *metallism* in which the value of currency depends on its intrinsic value or backing anchor.

(4) The intellectual concept under which the empirical concept of money falls is therefore the concept of a thing which, in the circulation of possessions (*permutation publica*) determines the price of all other things (goods), among which even the sciences belong, insofar as they would not otherwise be taught to others. The amount of money in a nation therefore constitutes its wealth (*opulentia*). For the price (*pretium*) of a thing is the judgment of the public about its value (*valor*) in proportion to that which serves as the universal means to represent reciprocal exchange of industry (its circulation) (Kant, 2017, p. 77).

(5) Money is therefore, according to Adam Smith, that material thing the alienation of which is the means and at the same time the measure of the industry by which human beings and nations carry on trade with one another. (Kant, 2017, p. 77).

This book, *the Metaphysics of Morals*, written in 1797, is about the law, and this section, (I) private right, handles civil law in a broad sense. As we read what Kant wrote on money, he did not accept the commodity theory of money. He took the labour theory of value from Adam Smith. But he also admitted money as a transferable item (credit or debt) and money was given in exchange for labour. This is closer to the credit theory of money. He was clear that money has no value in itself but can buy all goods. Because of the labour theory of value, the relative prices of goods and services and the relative wages of production and services could be determined.[11] He also insisted that nation's wealth could be represented by the money in circulation, which was interpreted as an early form of macroeconomics. He briefly mentioned that where there is a great deal of trade, neither gold nor copper is regarded as strictly money but only as merchandise, since there is too little gold and too much copper for them to be easily put into circulation and yet available in sufficiently small parts, as is necessary for the exchange of merchandise, or a mass of it, in the smallest purchase (p. 77). This story was commonly known as shortage of small changes in medieval times.

Kant was not an economist. But his understanding of economics in general and money in particular was quite clear and up to date or even exceeded his contemporary economists.

1.3 Fiat Money

Kant rejected paper money or, more precisely, fiat money, stating that "bank notes and promissory notes cannot be regarded as money, although they can substitute for it temporarily; for they cost almost no industry to produce and their value is based solely on the opinion that they will continue as before to be convertible into hard cash; but if it is eventually discovered that there is not enough hard cash for which

[11] Kant did not make a distinction between the goods market and the labour market. He seemed to understand that labour value can determine all relative prices both in goods and labour markets.

they can be readily and securely exchanged, this opinion suddenly collapses and makes failure of payment inevitable"(Kant, 2017, p. 76).[12]

According to Starr (2012), fiat money is defined as (i) inconvertible token currency promulgated by the state; and (ii) inconvertible token currency (not necessarily enforced by the government). The first definition is the focus of the chartalist school; the role of government is explicit. The second definition enters into many twentieth and twenty-first century formal models without explicit treatment of government (op. cit., p. 6).

Fiat money is nowadays a common form of money, especially after August 15, 1971, when Richard Nixon, the 37th President of United States of America, announced the halting of the U.S. dollar's convertibility to gold. The delinking of money with gold effectively turned the major currencies, including the U.S. dollar, into fiat money. Foreign exchange rate became floating since February 14, 1973, as a consequence.

Historically, fiat money had been issued from time to time—for example, in 1690, the Massachusetts colonial government issued fiat money. But as far as the nationwide monetary experience was concerned, the French government's introduction of fiat money on December 24, 1718, initiated by a Scottish policy projector, John Law, is worth discussing.

Many popular books on money quote the episode of John Law—for example, Martin (2014), Coggan (2012), and Orrell (2020). Here, I would like to summarize that episode and the lessons from it.

John Law[13] was 34 years old in 1705. He studied commerce and policy projects (recommendations) for the governments in London. He published his treatise on money, *Money and Trade Considered, with a Proposal for Supplying the Nation with Money* in 1705. This book is profound and modern in the sense that Law considered (1) the nature of money, (2) the relationship between money and trade, and (3) the policy issue of how to produce a new monetary structure capable of expanding the money supply. Truly, this was an early macroeconomic structural model in which money and the real economic activities were highly integrated.[14] Law believed that monetary expansion would generate increases in trade, employment and output. His macroeconomic system can be summarized as follows,[15] "(1) Trade depends on money; (2) There is some proportional relationship between the amount of money in

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[12] This statement is somewhat surprising because Kant did not adopt the commodity theory, or *metallism,* but this is understandable because labour costs in paper notes or promissory notes are regarded as almost zero. Kant did not mention John Law and his episode in France in 1716–1720.

[13] Comprehensive and good biographies of John Law can be found in Murphy (1997) and Buchan (2018). See also Murphy (2009) for macroeconomic interpretations of John Law.

[14] Murphy (1997, p. 88) indicates that Law may have been influenced by Sir William Petty, who produced a remarkable embryonic macroeconomic framework in *Verbum Sapienti*, written in 1664. There, Petty presented the equality of national income and national expenditure and the distinction between the stock of wealth and the flow of income derived from such wealth.

[15] It is often said that Adam Smith was the founding father of modern economics because of his *Wealth of Nations* (1776). But reading Law (1705), changes my view of how economics was created and by whom. I am quite sure that no swindler (John Law was so described after the Mississippi bubble) could write such a lucid book on money. John Law was equipped with a macroeconomic

circulation and the number of people employed; (3) Money is required because it is used to pay the wages of the workforce; (4) Credit is not practicable unless the credit can be used to purchase goods and services demanded by the employed workers, and credit used in such a way becomes money; (5) A greater quantity of money employs more people than a lesser quantity." Murphy (1997, p. 89).

With this policy project, John Law appeared in France in 1715 when Louis XIV died after 72 years on the throne and his nephew, Philip, Duke of Orleans, was confirmed as Regent. Through the Duke of Orleans, John Law had a chance to implement his project.

The first part of his project was designed to address France's lack of a money supply sufficient for the needs of its economic potential. John Law persuaded the Regent to allow him to establish a General Bank, which issued bank notes for the first time in France. This bank adopted a convertibility of its notes with gold and silver. Law made the General Bank's notes able to be used to settle foreign trade, and the Regent announced that taxes would be payable using its notes. The Bank was successful and its notes began to circulate widely and to stimulate trade (Martin, 2014, p. 173). In December 1718, the General Bank was nationalized and named the Royal Bank, with additional authority. It was announced that the bank notes were delinked with its holdings of gold and silver coins. This was John Law's introduction of fiat money in France (ibid., p. 174).

The second part of his project was to improve the parasitic system of public finance and the unsustainable level of the public debt. In 1717, Law convinced the Regent to allow him to form a joint stock company, the Company of the West, and to award it the rights to develop French North America, where the vast and virgin territories were expected to yield huge business profits for the Company. Holders of sovereign bonds were invited to swap their debt claims for equity shares of the Company of the West. The bond holders were eager to exchange bonds for equity shares (ibid., pp. 174–175).

In August 1719, Law launched the last part of his project. The Company acquired the rights to collect all indirect taxes in France. Its revenues were collected from the entire French economy. At the same time, it announced its intention to buy up the remaining part of the sovereign debt. To absorb these transactions, the Company issued huge tranches of new equity. The Company's share price rose from 500 livres in May 1719 to over 10,000 livres in December 1719. This was known as the Mississippi bubble. Law had achieved a comprehensive swap of government debt for government equity. His economic system worked unprecedentedly well. The Royal Bank's notes became the legal tender, and gold and silver lost their status as the legal tender. The supremacy of bank money and the fiat standard was complete (ibid., p.175). Here, John Law's mission was complete. On January 5, 1720, John Law was appointed as Controller-General of the Finances of France.

As is usually the case with a bubble economy, Law's system did not work long. At the end of May 1720, Law's system disintegrated and Law was arrested. On

framework, quite similar to that of Keynes (1936) in *The General Theory of Employment, Interest and Money.*

June 1, gold and silver were restored as the legal tender. Many other financial and social arrangements reverted to old system that had been in effect before John Law. On December 1720, Law managed to escape from France in fear for his life. He eventually died on March 21, 1729, in Venice, Italy, at the age 57, one month before his 58th birthday.

In retrospect, John Law conducted a remarkable social experiment in the most important European kingdom, France. He believed that metal money did not help the economy, and that money and the real economy (production and employment) were tightly linked (non-neutrality of money). His macroeconomic framework was quite similar to what we use nowadays. The other policy tools such as debt-equity swap and M&A strategy that Law used were extraordinarily unique and modern. He was indeed the strategist of all time, projecting into the future.

As to fiat money, Law originally had the idea of a land bank in which land-backed money could be issued as a substitute for metal money. In France, Law stripped out all convertibility of money and created genuine fiat money without any backing by real assets. This allowed full freedom in a money supply decision. From Law's point of view, fiat money was linked with the national economy and the state's tax revenues from its economy.

His fiat money was based on the credit (state) theory of money.

I will discuss Bitcoin and other cryptocurrencies in Chap. 6. Bitcoin, for example, is simply a digital message without any backing assets or legal tenders. Nevertheless, it has been traded among cryptocurrency believers with substantial price volatility. In 2021, the president of El Salvador, Nayib Bukele, announced that El Salvador would become the first country to adopt Bitcoin as its legal tender. Some countries might follow El Salvador. This is the current situation concerning cryptocurrency. It is a very bold action of the independent state to adopt private money without knowing who is issuing it and without any collateral backing. It is a social experiment as to how money functions in a small country like El Salvador.

1.4 Intertemporal Substitution of Monetary Value

Recall the quotation of Kant at the beginning of this chapter. There is a statement that "this passion (accumulation of wealth) is attached especially to old people (as a substitute for their natural incapacity)". What does it mean? I interpret it to be that people need some transferable guarantee or promissory note to purchase goods needed in old age, when they can not work and earn wages as before. Some goods are perishable, so that they cannot be kept until old age.

The best credit theory of the money model was developed by Samuelson (1958). Figure 1.1 shows the overlapping generation model.

Samuelson (1958) states his problem that in a stationary population, what will be the intertemporal terms of trade or interest rates will spring up spontaneously in ideally competitive markets (ibid., p. 468). He assumes that men live in three periods:

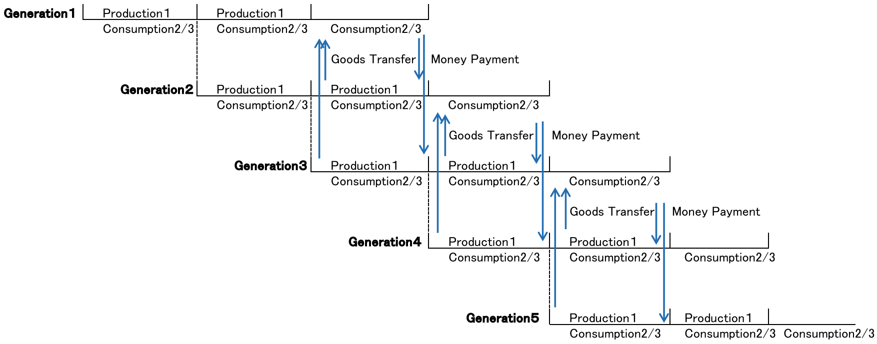

Fig. 1.1 Samuelson's overlapping generations model

men produce one unit of product[16] in period 1 (young) and period 2 (middle), and in period 3 (old) they retire and produce nothing. Products are perishable, so that consumers cannot save their products in period 1 and 2, and they consume in period 3. If the duration of each period is the same and a utility function is the same in every generation, how can men survive in period 3? Samuelson's answer is that the young can exchange one third of their product with the old generation and receive money (or promissory notes), the middle-aged generation can do the same with the old generation and receive money (or promissory notes). When the young generation reaches retirement age, they have money equivalent to two-thirds of products.[17] In this way, the money medium of exchange plays an efficient clearing arrangement or a savings instrument.

As to the interest rate, Samuelson obtains the result such that society by using money will go from a non-optimal negative-interest-rate configuration to the optimal biological-interest-rate configuration in which a real interest rate (i) is equal to the population growth rate (m). This is true even when $m < 0$, population falls and the desired real interest rate is negative.

Samuelson argues that money can bring the optimal allocation of resources over time. Without money or a social security system, this economic system is not sustainable. With a positive economic growth *cum* population growth, the real interest rate must be positive in this economic system. As we saw in the earlier section of this chapter, in Babylonia, loans attracted interest as a rate known as the *máš,* which meant "baby calf", money procreated just like farm animals. The ancient civilization admitted interest as a redistribution of surplus over the original products.

[16] As is evident from this assumption of 1 unit of product in each period, we do not expect any technological progress in the production process.

[17] Let us assume that the initial old generation has money equivalent to two-thirds of products. This assumption has an important implication that the initial issuer of money has the founder's profit as is the case with the Bitcoin founder. In addition, this mechanism of resource exchange between the young and the old resembles a pay-as-you-go social security (public pension) system. However, the pension is individually specific and not transferable to a third party. It cannot be considered as money.

Aristotle (*Politics*) was strongly against interest; “currency came into existence merely as a means of exchange; usury tries to make it increase. This is the reason why usury is called by the word we commonly use (*tokos*) for as the offspring resembles its parent, so the interest bred by money is like the principal which breeds it, and it may be called ‘currency the son of currency’. Hence we can understand why, of all modes of acquisition, usury is the most unnatural” (*Politics*, Vol.1. Chapter 10, 1258b). His view prevailed among the Western civilization as Thomas Aquinas placed Aristotle’s view in Christian divinity.

However, as time goes by, in the late eighteenth century, Industrial Revolution and institutional modernization took place in Britain and other European nations, Jeremy Bentham wrote *Defence of Usury* (1787) from view points of individual freedom and choice, risk premium, rejection of racial discrimination, among other reasons. Bentham strongly argued against the thought of Aristotle;

> In process of time, as questions of all sorts came under discussion, and this, not the least interesting, among the rest, the anti-Jewish side of it found no unopportune support in a passage of Aristotle: that celebrated heathen, who, in all matters wherein heathenism did not destroy his competence, had established a despotic empire over the Christian world. As fate would have it, that great philosopher, with all his industry, and all his penetration, notwithstanding the great number of pieces of money that had passes through his hands (more perhaps than ever passed through the hands of philosopher before or since), and notwithstanding the uncommon pains he had bestowed on the subject of generation, had never been able to discover, in any one piece of money, any organs for generating any other such piece. Emboldened by so strong a body of negative proof, he ventured at last to usher into the world the result of his observations, in the form of an universal proposition, *that all money is in its nature barren.* You, my friend, to whose cast of mind sound reason is much more congenial than ancient philosophy- you have, I dare to say, gone before me in remarking, that the practical inference from this shrewd observation, if it afforded any, should have been, that it would be no purpose for a man to try to get five per cent out of money– not that, if he could contrive to get so much, there would be any harm in it. But the sages of those days did not view the matter in that light” (Bentham, 1787, *Defence of Usury*, Letter X. “Grounds of the Prejudices against Usury”).

In the dawn of industrialization in the Western world, efficient allocation of money and capital were required. In so doing, all sorts of financial methods and institutions were developed. This movement gave birth to modern capitalism in which finance played the central role and financial innovation led a series of successful technological innovations.

Samuelson’s overlapping generations model can be interpreted as the credit theory of money. In his model, any transferable assets such as money, bonds, or promissory notes can be regarded as money in a broad sense. It may not be essential to distinguish money and bonds in this framework. Money can be regarded as a perpetual bond without interest, issued by the government. It is important that these transferable assets must be accepted by the third party. Here comes the issue of verification of credibility or creditworthiness of these assets regardless of fiat or commodity money. That is the most essential point in money.

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Chapter 2
On the Choice of Optimal Currency Denominations

2.1 Introduction

The innovation in currency such as digital money has been discussed worldwide. Digital money may replace coins and notes in a substantial way. Under such a circumstance as the coexistence of coins, notes and electronic money, a small distortion of coins and notes in terms of use-value would change the flow of money circulation to a great extent.

In this chapter, issues of different coins and notes in terms of denomination are determined seemingly by the Ministry of Finance.[1] But in fact, they are determined by the market mechanism in a broad sense. This is our basic framework as to how the choice of optimal currency denomination can be made.

In a textbook of monetary economics, money has three functions: medium of exchange, medium of account, and store of value. Actual coins and notes indeed have these three functions. At the same time, the relative use-value would differ among different coins and notes, thus the demand for coins and notes would differ.[2]

If money is a general good, differences in the use-value would be adjusted both in terms of price and quantity by the market mechanism. The price of money (legal tender) is fixed as its face value, thus there is no room for price adjustment. If the use-value or money demand among coins and notes differs, it would be a quantity that is adjustable.

Is currency denomination in Japan optimal? To begin with, can we define optimal distribution of currency denomination? If we can obtain the optimal distribution of

[1] In Japan as of 1996, in which this research was conducted, the Japanese government issued coins (1 yen 5 yen, 10 yen, 50 yen, 100 yen, 500 yen) and the Bank of Japan notes (500 yen; 1,000 yen; 5,000 yen; 10,000 yen).

[2] It is rare to find a person who is indifferent about paying 10,000 yen in 1-yen coins or in a 10,000 yen note. By the same token, it is rare to find a person who pays 1 yen with 10,000 yen note. The use-value of each coin and note would differ according to the size of payment, even though every coin and note can be used equally as a medium of exchange.

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currency denomination, how is the actual distribution distorted from the optimal one? Can we measure it?

To answer this question a priori, the optimal currency denomination is defined as the relative use-values of each coins and notes are set as equal, and thus relative demand for each coin and note is indifferent. The high use-value means that the buyer can settle his/her payment optimally by means of a minimum exchange of coins and notes (including changes). A distortion from the optimal distribution can be measured as the relative difference in actual circulation of coins and notes.

In the following section, we will discuss how to define the optimal currency denomination, how to measure a distortion from the optimal, and the policy implication for the actual circulation of coins and notes.

2.2 Optimal Distribution of Currency Denominations

How can we obtain the optimal currency denomination structure, based on the assumption that the relative use-values of all coins and notes are set equal and thus relative demand for each coin and note is irrelevant? The basic idea is to minimize the number of transactions (exchanges) of coins and notes given any payment amount. To do so, we need to identify the denomination structure (e.g., 1 yen, 5 yen, 10 yen, 50 yen, 100 yen, 500 yen, 1,000 yen, 5,000 yen,10,000 yen) to minimize the cash carrying cost in daily life. Telser (1995) discusses this problem. He argues that the problem of Bâchet, a famous problem in number theory, can help solve this problem. The problem of Bâchet seeks the smallest number of weights capable of weighting any unknown integer quantity between one and 41 on a two-pan balance. Telser restates the problem, assuming each weight costs the same, finds the least expensive set of weights that can weight any integer quantity between one and a finite upper bound. Hardy and Wright (1979) define the Bâchet problem in two cases: (a) when weights may be put into one pan only and (b) when weights may be put into either pan. The version pertinent to the currency denomination issue is applicable to case (b) because we usually allow changes to be made. Hardy and Wright (1979) obtained the solutions for both (a) and (b) cases. In case of (a), the weights should follow the powers of two (i.e., 1, 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024,..). In case of (b), the weights follow the powers of three (i.e., 1, 3, 9, 27, 81, 243…) up to the sum of the weights $1 + 3 + 9 + \ldots. + 3^k = (3^{k+1}-1)/2$, the upper bound.

It is clear that the unknown amount to be weighted corresponds to a retail transaction to be paid in cash. Allowing weights to go in either pan corresponds to making change. The weights that can weight any quantity between one and the upper bound correspond to the assumption that a retail transaction is equally likely to be anywhere between one and some finite upper bound. So the Bâchet problem itself corresponds the choice of optimal currency denominations as we see above.

In case of retail transactions, if change can be made, case (b) applies and if change can not be made (e.g., old vending machines or bus payments), case (a) applies. In the following, we will mainly discuss case (b). The concrete problem is to

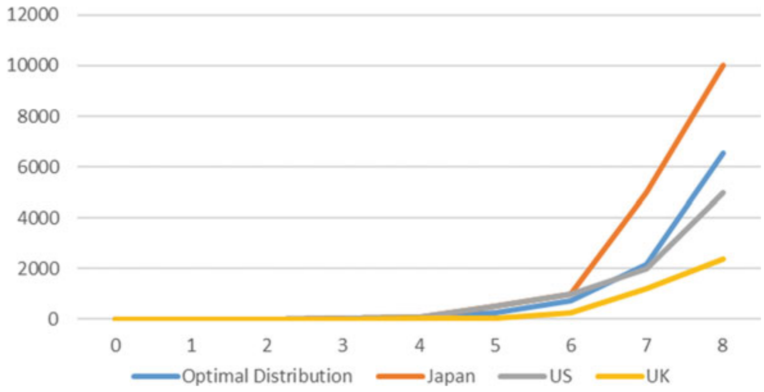

Fig. 2.1 Progressivity of currency denominations

determine the optimal denominations of coins and notes by way of minimizing cash holdings of consumers or cashiers in retail shops (e.g., supermarkets or convenience stores). In the Appendix, we will give a mathematical proof of the optimal currency denomination problem, as a natural extension of the Bâchet problem. Here we assume the distribution of transaction sizes are uniform.[3]

Figure 2.1 illustrates the progressivity of currency denomination in the US, the UK, and Japan and the optimal distribution (i.e., 3^k).

As Telser (1995) reports, distribution of currency denominations in the US is fairly close to the optimal distribution. Numerically, the arithmetic mean of progressivity of optimal distribution is 3.0 (power of 3) while it is 3.34 in the US. It was 3.52 for Japan and 2.53 for the UK. After $k = 6$, the progressivity accelerates in Japan and decelerates in the UK.[4]

Does the degree of progressivity exceeding 3 (the optimal level) in Japan create any distortions in circulations of coins and notes? See Table 2.1. The gap between the optimal and the actual denominations becomes clear when k = 3, 5, 7. The denominations will be approximately 25 yen, 250 yen and 2,000 yen, while the actual denominations take 50 yen, 500 yen and 5,000 yen. These denominations make progressivity higher than 3. Of course, if these denominations of coins and notes are used indifferently, there is no problem.

In order to identify the actual circulation of coins and notes, see Fig. 2.2. Surprisingly, circulation of 5 yen, 50 yen, and 5,000 yen are rather low, while circulation of the 500 yen coin is steadily increasing over time. In particular, that of the 5,000

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[3] If we look at individual prices, there is a tendency to quote prices ending in eight, nine or zero because it looks a bit cheaper (compare 102 yen vs 99 yen; people prefer 99 to 102. In fact, 3 yen difference would not matter from the retailer's point of view, so they set 99 instead of 102). Many goods are purchased all together and with value-added tax on consumption, but the distribution of final payments can still be assumed to be uniform.

[4] The arithmetic mean progressivity is calculated as an average of a set of solutions of (currency denomination) = (progressivity)^k ($k = 1, 2, 3, \ldots, 8$).

Table 2.1 Distribution of currency denominations

k	0	1	2	3	4	5	6	7	8	Degree of progressivity
Optimal distribution	1	3	9	27	81	243	729	2187	6561	3.00
Japan	1	5	10	50	100	500	1000	5000	10,000	3.52
US	1	5	10	25	100	500	1000	2000	5000	3.34
UK	1	3	6	12	30	60	240	1200	2400	2.53

Note (1) Figures are based on the minimum unit (yen in Japan, cent in US, penny in UK)
(2) In case of US and UK, old denomination coins and notes are omitted because they are rarely used
(3) In Japan, the distribution was before introduction of 2000 yen note in July 2000
(4) In UK, the distribution was before the decimal reform of February 1971

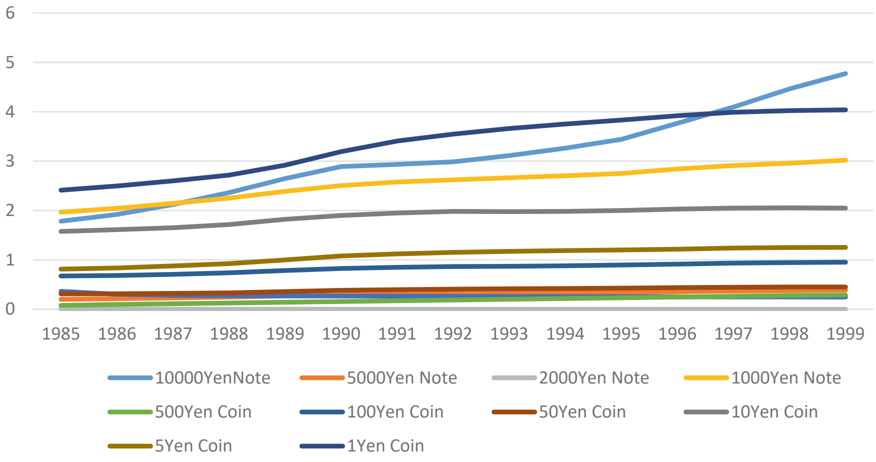

Fig. 2.2 Quantities of notes and coins in circulation. *Notes* (1) 500-yen note is omitted because of low circulation quantity. (2) The unit of notes is billion and that of coins is 10 billion

yen note is distinguishably lower than those of the 1,000 yen and 10,000 yen notes. Does this imply the use-value of the 5,000 yen note is very low?

By the way, how can we measure the use-value of coins and notes? It can be measured by the relative space among coins and notes. That is, in case of 1 yen and 5 yen, 1 yen is used when the payment is less than 3 yen and 5 yen is used when that is more than 3 yen. In other words, the use-value of the 1 yen coin is 3 yen because it is best used in a payment between 0 and 3 yen. That of the 5 yen coin is 4.5yen because the borderline between 5 and 10 yen is 7.5 yen.

Similarly, that of the 10 yen coin is 22.5 yen, the 50 yen coin is 45 yen, the 100 yen coin is 225 yen, the 500 yen coin is 450 yen, the 1,000 yen note is 2,250 yen, the 5,000 yen note is 4,500 yen, and the 10,000 yen note has no upper bound. The greater the denomination (face value), the larger the use-value becomes. We can standardize the use-value by dividing the denomination (face value). The standardized use-value

Table 2.2 Chi-square goodness of fit test

The relative ratio between coins and notes	5yen coin		50 yen coin		500 yen coin		5000 yen coin	
	1yen coin	10 yen coin	10 yen coin	100 yen coin	100 yen coin	1000 yen note	1000 yen note	10000 yen note
Chi-squired ration (χ^2)	3.106**	2.606**	30.626	0.522**	4.786*	16.652	204.247	253.574

Note (1) χ^2 (11) = 3.054 (*** = 1% significant level), 4.575 (** = 5%), 5.578(* = 10%)
(2) The theoretical value for 1yen coin is set $\mu = 3.3$

for a 1 yen coin is 3; those of a 10 yen coin, 100 yen coin, and 1,000 yen note are equally 2.25. That of a 10,000 yen note is infinity. Those of a 5 yen coin, 50 yen coin, 500 yen coin, and a 5,000 yen note are equally 0.9. That is, the use-value for a 10 yen coin, 100 yen coin, and a1,000 yen note is 2.5 times larger than that of a 5 yen coin, 50 yen coin, 500 yen coin, and a 5,000 yen note. This is a theoretical explanation for the low circulations of the 5 yen coin, 50 yen coin, and 5,000 yen note.[5] The relative use-value of the optimal denominations (i.e., the power of three, 3^k) is equally spaced 1.33 except for the minimum 1. This equality of the relative use-value is the fundamental reason for equal demand for the optimal denominations of coins and notes.

Let us turn to compare the relative ratio of actual coins and notes in circulation with the theoretical relative ratio of corresponding currency (i.e., 2.5). In so doing, we can understand how distortions from the optimal denomination structure can explain the actual circulations of coins and notes. We use the Chi-square goodness of fit test between the actual value and the theoretical value. This is one of the standard goodness of fit tests. The results are given in Table 2.2 for annual data 1984–1998.

$$\chi^2 = \sum_{i=1}^{k} (x_i - \mu)^2/\mu \text{ where } \mu = 2.5(\text{theoreticalvalue})$$

A 5 yen coin vis-à-vis a 1 yen coin and a 5 yen coin vis-à-vis a 10a yen coin are both theoretically consistent. A 50 yen coin vis-à-vis 100 yen coin is consistent with the theoretical value. A 50 yen coin vis-à-vis a 10 yen coin is not consistent with the theoretical value because a 10 yen coin in circulation exceeds the theoretical value. A 500 yen coin vis-à-vis a 100 yen coin is consistent with the 10% significant level. A 500 yen coin vis-à-vis a 1,000 yen note is not consistent with the theoretical value. A 5,000 yen note is not theoretically consistent with either a 1,000 yen note or a 1,0000 yen note—i.e., a 5,000 yen note in circulation is by far lower or both 1,000 yen and 10,000 yen notes in circulation exceed the theoretical value vis-à-vis a 5,000 yen note. In summary, while 5 yen, 50 yen, and 500 yen coins, with some exceptions,

[5] The high circulation of the 500 yen coin deserves further investigation.

are broadly consistent with the theoretical ratio, s 5,000 yen note in circulation is exceedingly low in value.

In the real world, coins and notes in circulation are determined not only by the relative use-values, but also by the average price levels and the average payment amounts per shopper. It may not be appropriate to conclude that 1,000 yen and 10,000 yen notes are widely circulated because of distorted use-values vis-à-vis a 5,000 yen note. On the contrary, low circulation of the 5,000 yen note, compared with all other coins and notes is clearly shown in Fig. 2.2. This is due to inappropriate choice of denomination spaces.

I raised the following question when I originally wrote in 1996: How about adding the 2,000 yen note for the current denomination structure? I thought that probably the 1,000 yen note, 5,000 yen note, and 10,000 yen notes would be substituted for by the 2,000 yen note to some extent and thus overall circulation of these notes would drop. In particular, substitution for the 1,000 yen note would be large and thus the relative distortion between the 500 yen coin and the 1,000 yen note would be corrected.

Lastly, excess circulation of 10,000 yen notes vis-à-vis 5,000 yen notes is not only due to a distortion between the two denominations, but is also due to no upper boundary above the 10,000 yen note. Due to the expansionary monetary policy in recent years, the circulation of 10 000 yen notes has steadily increased. We may think about the next denomination value above the 10,000 yen note. The Bâchet problem provides a clear answer for this. That is, the next denomination above the 10,000 yen note theoretically would be, $3^k = 3^9 = 19{,}683$ which is a 20,000 yen note in practice.

2.3 Conclusion

In recent years, policymakers in the government seem to adopt a market-based policy-making framework. They pay attention to economic deregulations and liberalization of the markets on the surface, but they rarely pay attention to such institutional distortions as discussed in this chapter. As is discussed in the framework of comparative institutional analysis, an institution affects other institutions (this is called institutional complements). Deregulation of a part of market may not be so effective because other parts of markets complement the deregulated part. Non-optimality of currency denominations may cause unnecessary cash hoarding costs, and price level concentration around certain digits (e.g., 3,990 yen for UNIQLO jeans) may also cause distortions in cash hoarding. Adjusting currency denominations to the optimal spacing is certainly a part of market-based policy making.

The Bâchet problem falls in the field of number theory in mathematics, which was described as the queen of pure mathematics by Carl Friedrich Gauss. Application of this problem almost directly to an economic problem is surprising, because in social science, rigorously controlled experiments are basically impossible. Cryptocurrency or cryptoassets use, by definition, cryptographic techniques which are also based on the field of number theory. Given that the market economy is fundamentally based on the world of natural numbers (i.e., 1, 2, 3,…), the analysis of the market economy may adopt more results from number theory.[6]

2.4 Appendix: Application of the Bâschet Problem to the Choice of Optimal Currency Denominations

The Bâschet problem can be interpreted as equivalent to the choice of optimal currency denomination, setting different denominations to minimize transactions of coins and notes between buyers and sellers. We can consider either the case of allowing changes or that of allowing no change. We will focus on the case with change, which is more general. The solution is divided by two sections: (1) We can pay any amount by combining different denominations of coins and notes (Lemma 1) and (2) There exist the optimal denominations of coins and notes to minimize transactions (Theorem1). Proof of theorem 1 is based on Hardy and Wright (pp.116–117, theorem 141).

Lemma 2.1 Given denominations, $k_0, k_1, k_2, \ldots, k_n,$ any positive integer (payment) a can be expressed uniquely as a combination of denominations, allowing changes.

$$a = e_0k_0 + e_1k_1 + e_2k_2 + \cdots + e_nk_n \tag{2.1}$$

where $e_i can\ take\ any\ number\ including\ 0\ and\ negative\ (in\ case\ of\ changes).$

Proof Divide a by k_1 and yield quotient Q_1 and remainder e_0k_0.

$$a = e_0k_0 + Q_1k_1(0 \leq e_0k_0 \leq k_1) \tag{2.2}$$

Then divide Q_1k_1 by k_2 to yield the quotient $Q_2$and remainder e_1k_1.

$$Q_1k_1 = e_1k_1 + Q_2k_2(0 \leq e_1k_1 \leq k_2) \tag{2.3}$$

Repeat the same procedure,

$$Q_{n-1}k_{n-1} = e_{n-1}k_{n-1} + Q_nk_n(0 \leq e_{n-1}k_{n-1} \leq k_n) \tag{2.4}$$

Substitute (2.3) and (2.4) into (2.5), to yield

$$a = e_0k_0 + e_1k_1 + e_2k_2 + \cdots + Q_nk_n \tag{2.5}$$

Incidentally, k_n is the highest denomination at which Q_n can be replaced by e_n.

[6] Certainly, Hardy and Wright (1979) is filled with real-world problems and their solutions. Many issues can be applicable to economic issues.

$$Q_n k_n = e_n k_n (0 \leq e_n k_n) \tag{2.6}$$

Substitute (2.6) into (2.5), to yield

$$a = e_0 k_0 + e_1 k_1 + e_2 k_2 + \cdots + e_n k_n = \sum_{i=0}^{n} e_i k_i \tag{2.7}$$

Equation (2.7) implies that $e_{n\text{-}1}$ minimizes $e_{n,}$ and in turn, $e_{n\text{-}2}$ minimizes $e_{n\text{-}1}$ and so on. Given denominations, k_0, k_1, k_2, ...,$k_{n,}$, e_0, e_1, e_2, ...e_n are the minimum number of integers to make payment *a*. (Q.E.D.)

The most efficient (non-redundant) way of using currency denominations n + 1 is the case where e_i takes 0, –1, or 1. This case satisfies the condition of denominations following the powers of three. Proof is given in the following.

Theorem 1 Allowing changes, currency denominations 1, 3, 3^2, 3^3, 3^4, …0.3^n can pay any amount (integers) up to (3^{n+1} – 1)/2 and transactions of coins and notes for this payment becomes minimum.

Proof From Lemma 1, any positive integer *a* (upto $3^{n+1} - 1$) can be expressed uniquely as a weighted sum of the ternary scale.

$$a = \sum_{i=0}^{n} f_i 3^i \tag{2.8}$$

where every f_i is 0, 1, or 2. And

$$b = \sum\nolimits_{i=0}^{n} 3^i = (3^{n+1} - 1)/2 \tag{2.9}$$

Subtracting (2.9) from (2.8), $c = a–b$, we see that every positive or negative integer between –(3^{n+1}–1)/2 and (3^{n+1}–1)/2 inclusive can be expressed uniquely in the form

$$\sum\nolimits_{i=0}^{n} g_i 3^i \tag{2.10}$$

where every g_i is –1, 0 or 1. Hence our currency denominations (n + 1 different coins and notes), allowing changes, will pay any amount up to $(3^{n+1} - 1)/2$ by using only one (maximum) denomination each.

Now we turn to proving that no other combination of n + 1 denominations can pay the same amount as efficiently (small transactions) as a weighted sum of the ternary scale.

Currency denominations k_i differ and are put in order such as

$$k_0 < k_1 < k_2 < \ldots < k_n \tag{2.11}$$

The two largest amounts using one denomination each are plainly

$$W = k_0 + k_1 + k_2 + \cdots + k_n \tag{2.12}$$

$$W_1 = k_1 + k_2 + k_3 + \cdots + k_n \tag{2.13}$$

The difference between W and W_1 must be 1 ($k_0 = 1$). The next largest amount is.

$$W_2 = -k_0 + k_1 + k_2 + \cdots + k_n = W - 2 \tag{2.14}$$

The next one is.

$$W_3 = k_0 + k_2 + k_3 + \cdots + k_n = \mathrm{W} - 3 \tag{2.15}$$

That is, $k_1 = 3$. Suppose that we have proved that

$$k_0 = 1, k_1 = 3, \ldots, k_{s-1} = 3^{s-1} \tag{2.16}$$

The largest amount W can be expressed as is

$$\mathrm{W} = \sum\nolimits_{t=0}^{s-1} k_t + \sum\nolimits_{t=s}^{n} k_t \tag{2.17}$$

Leaving the denominations $k_s, k_{s+1}, \ldots, k_n$ undisturbed, and removing some of the smaller denominations, or transferring them to changes, we can pay up to the minimum amount,

$$-\sum\nolimits_{t=0}^{s-1} k_t + \sum\nolimits_{t=s}^{n} k_t = W - (3^s - 1) \tag{2.18}$$

but none below.

The next denomination less than this is $W - 3^s$, and this must be

$$k_0 + k_1 + k_2 + \cdots + k_{s-1} + k_{s+1} + k_{s+2} + \cdots + k_n \tag{2.19}$$

Hence

$$k_s = 2(k_0 + k_1 + \cdots + k_{s-1}) + 1 = 3^s \tag{2.20}$$

For all positive integers n, $k_n = 3^n$ holds by induction (Q.E.D.)

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Chapter 3
The Impact of Denomination Choice on Commercial Trading: A Policy Evaluation of a New Iraqi Monetary System

> So he saluted him and Ma'an said to him "What bringeth thee, O brother of the Arabs?" Answered the Badawi, "I hoped in the Emir, and have brought him curly cucumbers out of season." Asked Ma'an, "And how much dost thou expect of us?" "A thousand dinars," answered the Badawi. "This is far too much," quoth Ma'an. Quoth he, "Five hundred." "Too much!" "Then three hundred." "Too much!" "Two hundred." "Too much!" "One hundred." "Too much!" "Fifty." "Too much!" At last the Badawi came down to thirty dinars; but Ma'an still replied, "Too much!" So the Badawi cried, "By Allah, the man who met me in the desert brought me bad luck! But I will not go lower than thirty dinars." Quoted from the 271th Night, "Ma'an Son of Zaidah and the Badawi", from *the Book of The Thousand Nights and a Night*, Vol. 4 by Richard F. Burton, Shammar Edition, 1885.

3.1 Introduction

Ever since 1991, the Gulf War, starting the invasion of Iraq to Kuwait, economic sanctions were imposed on Iraq for a long time and oil exports, which was the major source of foreign currency, were also restricted. As a result, the Iraqi government lacked fiscal revenues, thus faced large fiscal deficits. Inevitably, the government financed its expenditures by printing money as exchanges of government bonds. The nation experienced a rapid inflation, as we can easily imagine. The Saddam Hussein regime collapsed after the Iraq war in March 2003. Under the interim Iraqi Administration, new Iraqi dinar notes were issued and replaced old notes between October 15, 2003, and January 15, 2004, in three months.

This chapter considers the role of currency under a rapidly changing society in Iraq. In particular, we will focus on the new currency regime after January 15, 2004.

After the Gulf War in 1991, no reliable macroeconomic statistics were available except for a part of the UN statistics. We can use the information only on currency denominations and fragmentary price data. Iraqi currency dropped to ten-thousandth its value over 10 years' economic chaos following the Gulf War, economic sanctions, and the Iraq War. In order to evaluate the Iraqi currency system in the future, we shall use an appropriate exchange rate under normal circumstances, not an extremely undervalued exchange rate under the chaotic economic conditions. This chapter was

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originally written in August 2004. We did not have sufficient information on macroeconomic statistics to understand the normal economic activity in Iraq. This chapter handles a very limited part of the problems the Iraqi economy faced at that time.

The chaos in the Iraqi economy can be understood as follows. In general, economic institutions normally evolve from the primitive stage to the matured stage. In Iraq, the modern economic institutions under the British Occupation during the First World War were introduced and functioned rather well. After independence in 1932, the Socialist Revolution in July 14, 1958, and Saddam Hussein's regime in July 16, 1979, economic institutions gradually deteriorated. Iraq's fundamental economic problems rest on malfunctioning of economic institutions in general and on the inability of the administration to understand the problems and inability of fixing them in particular.[1] That is to say, when facing the process of collapsing economic and social order, how can we amend and improve a new economic and social order?

Restricted to the currency system, if there is a regime change in a fundamental sense, a new currency system should be introduced to replace the old system. The government imposes deposit freezing of the old currency, encourages renegotiation of the old economic contracts in general, debt contracts in particular, and debtors repaying debt in a full or in a discounted amount.

The Iraqi currency reform was conducted in three months under the coalition provisional authority. Although the old currency was replaced by the new currency, old economic contracts were untouched. The exchange rate between the old and the new currency was fixed at 1:1. Consequently, economic impacts of the new currency system remained limited.

An exception was to unify the two currency systems prevailing in the Kurdistan Region, i.e., the old Iraqi currency and the Swiss dinar currency[2] with the exchange rate at 1:150. This currency unification with the Kurdistan region was noteworthy. Of course, as we all know, the situation was not that simple. In recent years, the 2017 Kurdistan Region independence referendum took place on September 25, with 92.73% voting in favor of independence. This triggered a military operation in which the Iraqi government retook control of Kirkuk and surrounding areas and forced the Kurdistan Regional Government to annul the referendum.

Going back to 2004, many money changers around Al-Kadhimiya Mosque actively traded in various currencies with a fixed handling fee of 2%. Money changers decided the exchange rates among currencies, willingly including the US dollar, Iranian rial (toman), Swiss dinar, and Saddam dinar, which were not necessarily at the rates in the Foreign Exchange Market. Because of the introduction of the new currency and anti-US sentiment, dollarization did not happen. Money changing was an attractive business with foreigners, given the normal economic activity did not occur.

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[1] Similar problems were found in many Asian and African countries that obtained independence after the Second World War.

[2] This was the currency introduced before the Saddam Hussein regime, for which the original plates for banknotes were engraved in Switzerland and thus was called the Swiss dinar.

The new currency system included six denominations (50, 250, 1,000, 5,000, 10,000, and 25,000 dinars). As the minimum denomination of the old Saddam dinar was 250 dinar, the minimum denomination dropped to 50 dinars in the new currency system and difficulties with small payments were eased. However, it remained a big problem without smaller change below 50 dinars. In this chapter, we consider the small change problem in which small denominations are not available in market transactions. This problem was well known in medieval Europe, as discussed by Sargent and Velde (2002).[3] The same problem has happened in Iraq in recent years. In medieval Europe, it was said that the rulers did not have any incentive to provide small coins (denominations). In Iraq nowadays, it may be true that the costs of providing small coins (denominations) exceed the face value of the coins. That is, these small coins would not yield any seigniorage. As of April 24, 2004, the exchange rate was 1 dollar = 1,150 dinars, 100 yen = 1,077.43 dinars (approximately 50 dinar = 5y en). It may not be a big problem to ignore denominations below 50 dinars.

If this circumstance continues, this argument can be valid. But in 1991, just before the Gulf War, the exchange rate was 1 dinar = 3.22 dollars = 436 yen. 50 dinars was equivalent to 21,800 yen. It was a sufficiently large amount and it may not be the case that we can ignore any amount below 50 dinars. In this case, we may need to consider supplementary coins (5, 10, 25, and 100 fils as 1 dinar = 1,000 fils).[4] If Iraq could concentrate its effort on recovering the economic and social system as it was before the Gulf War, its economic activity would be at least as high as that before the Gulf War period. It is necessary to prepare small denominations (coins and notes) below 50 dinars.

Furthermore, in principle, without the basic unit of accounting, 1 dinar, payable amounts are largely restricted. That creates non-negligible distortions in small payments (transactions). Imagine, with the current purchasing power, you can drink a cup of tea with 50 dinars; a lot of other goods and services can be purchased at lower than 50 dinars. It is difficult to make payment in multiples of 50 dinars if a priori quantity adjustment is not feasible with daily-use goods like gas, water, and electricity. In order to make payment exactly and flexibly, the basic unit of account, 1 dinar, is needed. To put it differently, introduction of the basic unit, 1 dinar, would make small payments easier by far, given the inconvenience and distortions without small denominations (change). We will come back to this problem in Sect. 3.3.

[3] In Japan, the central government (Bakufu) did not mint small coins; the merchants imported Chinese coins and used them regardless of the exchange rate.

[4] Currently supplementary coins (fils) in Iraq were not used because of high inflation.

3.2 History of Iraqi Currency System and the Facts

3.2.1 History of Iraqi Currency Denominations

In this section, we look at the history of Iraqi currency system. In 1831, the Ottoman Empire managed to overthrow the Mamluk regime and again imposed their direct control over Iraq. During the Ottoman rule, the Ottoman pound was the legal tender. Nonetheless, actually the Indian rupee, which was linked to the British pound sterling, was most widely circulated in the market. After colonization of the Ottoman Empire, the British government adopted the Indian rupee as the official currency in Iraq and consequently abolished the Ottoman pound. This was, in modern terms, equivalent to the dollarization of Iraq.

In 1932, the monarch Faisal I of Iraq (1885–1933) achieved independence from the British Mandate and the Iraqi dinar went into circulation on April 2, 1932, replacing the Indian rupee. The Central Bank of Iraq was established on November 16, 1947. After the Iraqi Revolution on July 14, 1958, the design of the bank notes was changed, but the currency denomination structure remained the same.

At that time, under the strong British influence, coins were minted at the Royal Mint, bank notes were printed at De La Rue. Both were British companies. Coins were introduced from 1932 to 1990 and in denominations of 1, 5, 10, 25, 50, 100, 250, 500 fils and 1 dinar(= 1,000 fils). Banknotes were issued in denominations of ¼, ½, 1, 5, 10, 50, 100,and 250 dinars. In 2003, new banknotes were issued consisting of six denominations; 50, 250, 1,000, 5,000, 10,000, and 25,000dinars. These denominations of coins and banknotes in 1982 included the coins for a commemorative series celebrating Babylonian achievements and small face-value banknotes (i.e., less than 10 dinars) were taken out of circulation. De La Rue issued a 25 dinar note in 1986, bearing an idealized engraving of Saddam Hussein, then president of Iraq.

Following the 1991 Gulf war, Iraq was divided into the region controlled by Saddam Hussein in the south and the Kurdish region in the north. The UN Security Council adopted Resolution 661, which imposed economic sanctions on Iraq. As a result, the British Royal Mint and De La Rue withheld their business with Iraq. Iraqi currency was printed both locally and in China, using poor-grade wood pulp paper and inferior offset printing. Its denominations were 5, 10, 25, 50 and 100 dinars without any counterfeit technology. On May 5, 1992, the Iraqi government announced that because foreign countries had provided counterfeits of Iraqi currency and tried to destroy the Iraqi economy, the popular 50 and 100 dinar notes would no longer be used.

In May 1993, Iraq closed its border with Jordan and abolished the De La Rue 25 dinar note. This note was very popular, so that it acquired a premium value. Jordanian merchants hoarded the De La Rue 25 dinar notes on a large scale and lost 1.5 billion dinars.[5] Replacement of the old currency by the new currency took place in only

[5] The purposes of this border closing were to make Iraqi currency in foreigners' hands useless, to reduce the amount of currency circulation, and thus to maintain the value of Iraqi currency.

three weeks, beginning May 5, 1993. While currency in circulation was 22 billion dinars in 1991, in 1995 climbed to 584 billion dinars. As a result, the annual average inflation rate shot up 250%. Small face-value notes and coins became valueless, and only the 25 dinar note was used in cash transactions.

Iraqi Kurdistan in the north hoarded 5 billion old Swiss 25 dinar notes[6] out of the total 7 billion in Iraq. It was circulated without replacement by the Saddam dinar. The Swiss dinar had not been issued since 1989. The Central Bank in charge of issuing the Swiss dinar no longer existed. It was fiat money without any guarantee from the government or the Central Bank. Nevertheless, the remaining notes kept circulating in the market. This was a rare event in monetary history. Furthermore, the Swiss dinar had a higher quality than the Saddam dinar, used anti-counterfeit techniques, and thus had a lower counterfeit risk premium.[7]

Look at the exchange rate between the Swiss dinar and the Saddam dinar: as of July 1997, it was 60 Saddam dinars = 1 Swiss dinar. Over time, the rate dropped to 200–400 Saddam dinars = 1 Swiss dinar after July 2002. When the Saddam Hussein regime collapsed in March 2003, it was 300 Saddam dinars = 1 Swiss dinar. This phenomenon can be explained by the fact that the exchange rate reflected the balance between the fixed-amount Swiss dinar and the ever-increasing (money supply) Saddam dinar.

How can we explain that the exchange rate between the Swiss dinar, which was not-supported by the Iraqi government, and the US dollar was 1 dollar = 18 Swiss dinard in May 2002 and rose to 1dollar = 6Swiss dinars after the Iraq War ended in May 2003? As King (2004, pp. 8–9) argues, that appreciation reflected expectations about (1) the durability of the political and military separation of the Kurdish region from Saddam-controlled Iraq and (2) the likelihood that a new institution would be established governing monetary policy in Iraq as a whole that would retrospectively back the value of the Swiss dinar. However, the government that issued the Swiss dinar no longer existed and the Central Bank of Iraq did not guarantee the exchange between the Swiss dinar and the Saddam dinar. The value of the Swiss dinar had everything to do with policies and nothing to do with the economic policies of the government issuing the Swiss dinar.

The Iraq War begun in March 2003 and the Saddam Hussein regime collapsed in May 2003. In July 7, 2003, Paul Bremer, Interim Civil Administrator (the head of the Coalition Provisional Authority), announced that a set of new Iraqi dinars (50, 250, 1,000, 5,000, 10,000, 25,000) would be printed and exchanged for the two existing currencies (i.e., 250 10.000 dinars) at a parity rate (i.e., 1 to 1) and 1 Swiss dinar = 150 new dinars The exchange was to take place over the period from October 15, 2003, to January15, 2004. The design of the new dinars was similar to the notes

[6] This banknote was printed in British De La Rue, but the original picture plate was engraved in Switzerland. It is called the Swiss dinar.

[7] On the contrary, the Saddam dinar under the economic sanctions, was made with very primitive printing techniques, and counterfeit banknotes, in particular 1,0000 dinar notes, often appeared. This note was rarely accepted in practice due to fears of looting and counterfeiting. This forced the Iraqi people to use 250 dinar banknotes for daily shopping.

issued by the Central Bank of Iraq in the 1970s and 1980s, given a very short time of preparation and printing by De La Rue.

As discussed before, the minimum denomination being 50 dinar (about 5 yen) had to do with the manufacturing cost. It is said that 1 banknote costs 10–20yen to produce in Japan. If the cost is similar to this, 100 dinar (about 10 yen) would be the profit line. A lower denomination than 100 dinar might generate losses (negative profit) so that the smaller denominations might not be feasible.

The exchange rate between the Swiss dinar and the Saddam dinar was 1:150 in September 2002. It shot up to 1:300 at the beginning of the Iraq War on March 20, 2003, and converged to 1:150 on the day the new currency system was announced, July 7, 2003. King (2004, p. 10) elaborated that the exchange rate hovered above 150 after parity was announced on July 7, considering (1) the counterfeit risk premium on the Saddam dinar, and (2) before the capture of Saddam Hussein in December 2003, some uncertainty about the prospects of the new regime and the new currency system was inevitable.

King's final remark on this episode is worth quoting: "The value of money depends on beliefs about the probability of survival of the institutions that define the state itself." (King, 2004, p. 10).

3.2.2 Price Level and Exchange Rate in Iraq

As discussed above, comprehensive economic statistics after the Gulf War in Iraq did not exist. Only partial and insufficient data were available. UN National Account statistics were available only in nominal value. The nominal GDP growth in 1990 was 10.79%, in 1991 was –14.42%, in 1992 was 148.04%, in 1993 was 151.68%, in 1994 was 395.02%, in 1995 was 214.99%, in 1996 was 22.58%, in 1997 was 37.43%, in 1998 was 39.76%, in 1999 was 49.01%, and in 2000 was 8.65%.

During this period, the Iraqi economy experienced hyper-inflation. It was said that the real GDP dropped by 57% between 1989 and 1992 and that it reached the level of the 1970s (of course, these are not exact statistics). Suppose the real GDP growth rate was 0%: the nominal GDP growth rate actually reflected the inflation rate. From 1992 to 1995, there were a strong signs of hyper-inflation.

We can observe this phenomenon from information on the household income. According to one source, a high-ranking bureaucrat's monthly salary was 775 dinars in 1993, reaching 5,000 dinars in 1996 and further increasing to 50,000–100,000dinars later. Supplementary information shows that the average monthly expenditure on food for a six-member household was 5,400 dinars in 1993. It is easy to imagine that the standard of living would be very low even if two or three members of the household worked.[8]

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[8] After the Iran–Iraq war, rationing of basic goods was stopped. After the Gulf War, it was resumed. The rationed materials included wheat (9 kg), rice (3 kg), vegetable oil, sugar, salt, tea, and detergent.

Inflation was reflected in the exchange rate. From this perspective, the exchange rate was 1 dinar = 3.39 dollars in 1979, when Saddam Hussein became the president and chairman of the Revolutionary Command Council in Iraq. 1 dinar = 3.2164 dollars in 1985, 3.2249 dollars in 1990, Until then the exchange rate had been very stable. But in 2003, it dropped to the level of 1 dollar = 4,000dinars (1 dinar = 0.00025dollar = 0.025cents), 1/13560 of its earlier value. Immediately after the Gulf War in 1991, it dropped to 1/600 of its value. However, the exchange rate recovered to 1 dollar = 1,150dinars on April 24, 2004. The value of the Iraqi dinar increased four times from its level in 2003.

The fluctuation of the exchange rate cannot be explained by the inflation rate of a country, because it is essentially a relative measure. Suppose the inflation rate of the US in the 1990s remained very stable, *ceteris paribus*; Iraq experienced more than a 100% inflation rate *per annum*. From another source, it is said that before the Gulf War, the annual average inflation rate was 45%; after the war, it shot up above 500%. It may not be badly wrong to assume a 100% inflation rate *per annum* during the 1990s. For those who stayed in Iraq during and after the Saddam Hussein regime, all monetary transactions took place only by means of the 250 dinar note (the 1,000dinar note was rarely used). Smaller- denomination coins were not used at all. We have only partial information on individual prices of goods and services and we do not know how these prices represent the whole economy. For example, 1 kg mutton was 3,000 dinars before the Iraq War (2003) and 8,000dinars after the war. Three eggs were 250 dinars before the Iraq war and 450 dinars after the war. 1 piece of pita bread was 25 dinars before the war and 50 dinars afterward. After the Iraq war, the price levels became double. The prices were adjusted in multiples of 250 before the war and in the multiples of 50 after the war because of the availability of minimum denominations. If a unit price was below the minimum denomination, units were bundled quantitatively to make a price, multiples of the minimum denomination.

3.3 Use-Value of the New Currency System in Iraq and Its Problems

A typical pattern of shopping before the new currency system (i.e., two currency denomination system) went as follows. If you were not Iraqi, you exchanged your 100 dollars, for example, for 250 dinar banknotes (about 25 yen), then you received 1,000–2,000 in 250 dinar notes (usually 10–20 blocks in a bundle of 100 notes) in a plastic bag. You shopped with those. Until January 2004, only 250 dinar notes were circulated in the market. Payments were made in multiples of 250 dinar notes. In case of a large payment, you could mix dollar notes with dinar notes. But in case of bundles of dinar notes, merchants checked only the numbers of the first and last note to assume a bundle contain a hundred 250 dinar notes.

This pattern of shopping inevitably became very rough because there were no high-denomination notes or low-denomination coins. In the following, let us discuss use-value of the new currency system in Iraq and its problem from theoretical viewpoints.

First of all, the economic price (producer price) of a good is determined by the marginal cost of its production, which is independent of the currency denomination structure. On the other hand, the monetary price (consumer price) is set at the payment stage, taking into account available currency denominations, tax, and other factors. Without VAT (consumption tax) and with a perfect competition in the market, the economic efficiency can be achieved by equilibrating the economic price and the monetary price. However, this condition is not satisfactory because the infeasibility of the payment amount due to limited denominations. We need to understand that a multiple of 250 is a very small portion of the natural number as a whole. It is clear how difficult it is to set a price under which the producer price and the consumer price may not coincide. Given currency denominations, we need to decide how to make a payment with these notes. As we experience daily, it is convenient for consumers to have many ways to settle a payment. With currency denominations in Iraq, there are far fewer ways to make payments than those with Japanese denominations (see Appendix 3.1). How do merchants set prices, given denominations? Merchants play a role as an intermediary between producers and consumers. If the currency denomination structure prevents flexible (marginal) pricing, the second-best solution would make quantitative adjustments to meet a payable amount with its denominations. Of course, quantity could easily exceed what a consumer wants. This type of pricing can be found in supermarkets and grocery stores.[9] In the Middle East, from my limited knowledge, the standard pricing in bazaar is to set prices for a unit amount (say, kilograms of meat, dozens of eggs, liters of milk). In this case, it could set prices for a payable amount by adjusting the unit (say, per 2 kg, per 2 dozen, per 2 L). However, merchants usually bargain the price up and down according the customers. This becomes possible under a bilateral trading (the bazaar system). In economic theory, this could be handled in the framework of non-linear pricing under which customers are differentiated according to consumption amounts or to long-term trade relationships.

Secondly, let us think about how Iraqi merchants reacted to the small-change problem, that is, a shortage of small denominations. In general, there could be three reactions: (1) disregard small change, (2) use alternatives to substitute for change. For example, use candy or foreign coins as substitutes for small change, and (3) record transactions in a trading account and settle them after a certain period for repeated customers. For (1), we could consider it as the merchant's pricing behavior. For (2), it is possible and we know this method was used in the past. We will not consider it here. For (3), it can be considered as a type of credit formation.

Thirdly, it may be awkward to consider small-dinar denominations when high inflation devalues the Iraqi dinar substantially. However, when inflation calms down

[9] Basu (1997) and Shy (2000) studied reasons that supermarkets tend to make prices like $99 and $299. This is not only a quantitative adjustment but also a psychological manipulation due to consumers' behavioral reactions.

and the exchange rate returns to the long-run parity level, the value of the Iraqi dinar would go back to the pre-Gulf War standard. In such a case, the Iraqi dinar would have a substantial purchasing power. For example, if the value of the dinar goes up to 100 times the current level, 1 dinar could easily reach 10 yen. For the same reason, without considering the long-run steady-state level, judging solely from the status quo, it is a highly questionable practice to insist that the current 50 dinar should be replaced by a new 1 dinar via rescaling the denominations.[10] It is understandable that the issue cost below the 50 dinar denomination may exceed the face value, so that the issuer (i.e., the government or the central bank) could not earn any seigniorage (may generate a loss to the government). Under this circumstance, if small denominations are issued in the form of metallic coins, these coins would be melted and sold for alternative uses, and we could expect that no metallic coins would be circulated in the market. To avoid this risk, small denominations should be issued in the form of (paper) banknotes. The banknotes will not be used for alternative purposes, and there would be no incentive to produce counterfeits, considering the substantial issue cost.[11]

3.3.1 The Ratio of Payable–Non-payable Amounts and the Ways of Payment in Payable Amounts

The first problem here is to consider a share of a multiple of S (the smallest denomination) over any natural number (N) that the payment amount may take. The total number by which the smallest denomination can generate is N/S. The share of the total number (N/S) over the whole natural number (N) can be expressed as

$$\frac{\frac{N}{S}}{N} = \frac{1}{S} \tag{3.1}$$

[10] In Japan, rescaling denominations is not fully understood. That is to say, we need to distinguish the case in which a country that experienced hyperinflation decided to replace an old 10,000 unit note by a new 1 unit note because the value of the old 10,000 unit note dropped so that it does not make any sense to consider the value below old 10,000 unit note. The case in which a country like Japan decides to replace the current 100 yen by a new 1 yen under the name of rescaling denominations, consumers in Japan can purchase many goods below the current 100 yen level so that the Japanese government must issue supplementary denominations below the new 1 yen. In the latter case, the replacement of the old currency by the new one, in principle, implies a rescaling of currency denominations and it does not change any methods of payments and quantities of currency in circulation. Note that the value of the minimum currency unit 1 cent in the US or the Euro zone is at parity, more or less, with that of the 1yen in a sense: the minimum purchasing power is set as equal among the major international currencies.

[11] Sargent and Velde (2002) pointed out that if the value of metallic coins is higher than the face value, there would be a possibility of their being melted, and if the value of coin is low, then people would refuse to accept it. The metallic value and the face value of coins must be balanced, if the issuer want metallic coins to be circulated normally. Historical episodes indicate that was difficult in reality.

Regardless of the upper limit of the natural number (N), the share is 1/S. Intuitively, if S = 250, you encounter a payable amount with 250 dinar denominations once in every 250 continuous natural numbers. In a numerical expression, 1/250 = 0.004 (0.4%). If the smallest denomination is 50, then 1/50 = 0.02 (2%). If that is 1, then 1/1 = 1 (100%), i.e., with the basic unit denomination (S = 1), you can pay any amount corresponding to the natural number.

If the smallest denomination is reduced from 250 to 50, consumers can pay five times more than before. However, the 50 dinar notes can pay only 2% of the potential amount.

The second problem is to find how many ways there are to settle payment amounts by means of currency denominations. As a rigorous mathematical argument is given in Appendix 3.5, if the payable amount is 1,000, in Japan there are 248,908 ways to pay, given the currency denominations (1, 5, 10, 50, 100, 500 yen coins). In Iraq there are only 6 ways to pay, given the available currency denominations (50, 250, 1,000 dinar notes). Of course, this difference may reflect a difference in the economic value of 10,00 yen and 1,000 dinar. Even for a high value such as 100 thousands or 1 million, it is true that Japanese consumers have more ways to pay than do Iraqi consumers. In general, the more ways you have to settle payments, the less you are restricted on holding denominations in hand. Flexibility of consumers increases as a result. In the case of Iraq, consumers must hold many 50 dinar notes to settle payments, it would be quite inconvenient for consumers in Iraq.

Replacing the old 50 dinar by the new 1 dinar, all prices are adjusted to express in any natural number via the new 1 dinar; however, these are in fact multiples of the old 50 dinar.[12] Retail shops may set prices being equal to a multiple of 50 dinar, the utilities like electricity, water, and gas are priced according to the basic quantities (e.g., price for 1 kw, 1 L, and 1 m^3), and consumption of these quantities may not reflect the payable amounts (multiples of 50 dinar). For the same reason, financial transactions and taxation may not satisfy payable amounts. In the process of globalization, international trading increases and Iraq imports a huge quantities of foreign goods and services, international trade settlements, adjusted through the exchange rate and expressed in the Iraqi currency denomination, may not necessarily be payable amounts.

[12] It is a method of rescaling denominations. As discussed earlier, under an unstable currency value, after rescaling the dinar denominations, a rapid exchange rate appreciation might occur, and a rapid deflation could follow as a result. Thus, if the government introduces a rescaling of denominations, it is desirable to do so in the period of a stable exchange rate. As a matter of practice, if commercial trades in Iraq do not require any currency denomination below 50 dinars, it makes sense to introduce a rescaling denomination in Iraq. If, on the other hand, it requires currency denominations below 50 dinars, supplementary small denominations (coins and notes) need to be issued. It is virtually the same as issuing smaller dinar coins and notes (e.g., 1, 5, 10, 25).

3.3.2 Pricing Under the Allowance of Infeasible Payment Amounts

Suppose the payment amount of a trade is X_i and it is paid by currency denominations. The payment amount is determined independently from the currency denominations. In principle, payment must be made by the smallest number of denominations.

$$X_i = aQ_1 + bQ_2 + cQ_3 + dQ_4 + eQ_5 + fQ_6 + g_i \tag{3.2}$$

where $Q_1 > Q_2 > Q_3 > Q_4 > Q_5 > Q_6 > g_i \geq 0$ Q_i is a currency denomination and g_i is a remainder, that is, an infeasible payment amount.

Equation (3.2) indicates that the optimal payment pattern can be expressed by one of the most fundamental theorems, i.e., the division theorem, in which given any integer and any positive divisor, there is always a uniquely determined quotient and remainder. The principle is simple. Pay as much as possible (a) by the maximum denomination (Q_1), as much as possible of the remainder is paid (b) by the second-largest denomination (Q_2). Repeat the procedure in descending order of Q_i. The optimal payment pattern means that minimum numbers of denominations are used for payment. If $g_i = 0$, the minimum positive value for X_i is equal to $\gcd(Q_i) = Q_6$, where gcd stands for the greatest common divisor (see Appendix 3.5). It is intuitively obvious when you think about a payment by means of currency denominations. That is, as $Q_6 = 50$ and there is no smaller denomination, the minimum payable amount must be 50.

The ratio of infeasible payment amount and total payment Z_i is defined as,

$$Z_i = \frac{g_i}{X_i} \tag{3.3}$$

where $0 \leq g_i < Q_6, 0 \leq Z_i < 1$

This ratio Z_i depends on the payment amount X_i. If X_i is a large amount, Z_i would be negligible. On the other hand, if X_i is a small amount, Z_i would be closer to 1. The problem occurs when the payment amount is relatively small, the ratio Z_i would not be negligible. For example, if the payment amount is 299 dinars and the infeasible payment amount is 49 dinars, then the ratio Z_i becomes 0.16388. If the merchant dismisses 49dinar from the payment, it implies that the consumer purchases goods or services with 16% discount.[13]

$$299 = 1 \times 250 + 49$$

$$Z_i = 49/299 = 0.16388 \tag{3.4}$$

[13] On the other hand, if the merchant raises the payment amount to 300 dinars, the consumer can pay the exact amount with 250 dinar and 50 dinar notes. The consumer loses 1/300 = 0.003 (0.3%).

Consumers may experience effective discounts and price increases (in case of raising the markup) within a certain range.

Let us think about a large payment amount. For example, to purchase 400 units of 299 dinar goods.

$$299 \times 400 = 478 \times 250 + 50 \times 2 \tag{3.5}$$

$$Z_i = 0/119600 = 0.00 \tag{3.6}$$

In this case, there is no infeasible payment amount, thus no discount.[14] As 50 dinars is the minimum denomination, if all trading units are fixed at 50, then all payment amounts can be payable without any remainder.

If the merchant dismisses the remainder or raises the price (marking up) or bunches goods just to avoid the remainder, the consumer may decide whichever payment method is most beneficial. For example, in the above dismissal case, the merchant dismisses 49 dinars for the payment of 299 dinars. The consumer is better off to purchase goods separately in the minimum units of 299 dinars, even if he or she wants 400 units. The consumer earns benefits of 19,600 dinars (= 49 × 400) by dividing the purchases. If there is no uncertainty about shortage of goods and the consumer is allowed to trade repeatedly, a large trade tends to be divided into many small trades.

However, this may not happen in the real world. That is, the merchant may notice that the same consumer purchases the same goods many times, so he or she reduces a discount rate or raises a price to eliminate benefits from the small trading.[15] The advantage in the bilateral transaction like those of the bazaar in the Middle East rests on observability of customers and the possibility of price and quantity bargaining between merchants and customers, as contrasted with anonymous trade in the supermarket. Economically, this bilateral trade is a system in which merchants would not lose or gain one-sidedly.

The merchant's price-setting behavior can be theoretically described as flows,

with long-time customers (N_α) and one-time shoppers (N_β). There is only one merchant and one set of goods (x) for consumers (N_α, N_β). Of course, there are many merchants and consumers in the markets. Neither monopoly nor monopsony exists. The long-time customers' demand for x is x_α, and his or her price elasticity of demand is ε_α. The one-time shoppers' demand for x is x_β and his or her price elasticity of demand is ε_β.

The consumer maximizes his or her consumption, given the budget constraint. We ignore substitutional consumption and prices of other goods.

$$\max U_i(x) s.t. y_i = p_i x_i \leftrightarrow x_i = V_i(p, y) i = \alpha, \beta \tag{3.7}$$

[14] Even for a small payment, if small payment amounts are booked and settled after a certain period, the case would be similar to a large payment case. This will be discussed later.

[15] As we will discuss below, the merchant treats long-time customers and the one-time shopper differently.

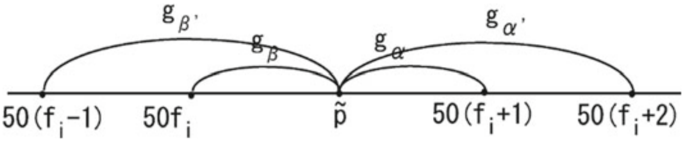

Fig. 3.1 Schedule for payable price

where $V_i(p, y)$ is an indirect utility function.

The long-time customer continues shopping at the same retail shop while many shops are available. In this case, the price elasticity of demand is lower than that of the one-time shopper ($\varepsilon_\alpha < \varepsilon_\beta$).

The self-employed merchant maximizes his/her profit, assuming that there is no other cost than the purchasing cost of goods.

$$\max\{\sum_{i\in\alpha,\beta} p_i x_i N_i - \tilde{p}\overline{X}\} \tag{3.8}$$

where $\tilde{p}$ is the wholesale price (producer price). The marginal cost is the average cost.[16] $\overline{X}$ is the total amount of goods x_i. The merchant knows the demand functions of both the long-time customer and the one-time shopper.

We need to consider an additional constraint, that is, the payable amount is restricted to a multiple of 50 dinars that is the minimum denomination.

Let us restrict the argument for small transactions in which we consider the wholesale price $\tilde{p}$ is divided into a multiple of 50 dinars (f_i) and a remainder part (g_i). i.e., $\tilde{p} = 50f_i + g_i$ where $f_i \epsilon \{0, 1, 2, 3, \ldots\}$, $g_i \epsilon \{0, 1, 2, 3, 4, \ldots .49\}$. The minimum payable amount above the wholesale price is $p = 50(f_i + 1)$ and the maximum payable amount below the wholesale price is $p = 50f_i$. See Fig. 3.1 for illustration.

Under perfect competition without any payment restrictions, the first best equilibrium price would be marginal cost = purchasing cost (wholesale price) $\tilde{p}$; all goods would be sold at that price. However, because of payment restrictions, the first best equilibrium price cannot be used; the merchant must set price $p = 50(f_i + 1)$ or higher for at least a part of his or her sales in order to avoid making losses.

It is inefficient, from the consumer surplus point of view, to sell goods at the same price when demand functions differ between the long-time customers and the one-time shoppers. Furthermore, other competitive merchants would try to steal some customers by selling goods at the lower price, $p = 50f_i$ which is below the wholesale price $\tilde{p}$. Under this circumstance, given two different demand functions, thus two different price elasticities of demand, the merchant sets prices following the Ramsey rule, in which the price is determined by a proportion to the inverse of price elasticity of demand ($\varepsilon_\alpha$and$\varepsilon_\beta$respectively) and a number of consumers

[16] According to Iwasaki (2004), the wholesale price (producer price) in the textile industry in Teheran, Iran, was so competitive that the merchants faced, more or less, the same price. We assume the wholesale price in Bagdad, Iraq, is the same for all merchants.

(N_α and $N_\beta$respectively) and by setting the price to level or to just exceed the purchasing cost (i.e., $\tilde{p} \times x_i$). That is, if the market is reasonably competitive and the wholesale price $\tilde{p}$ cannot be payable by denominations, the two or more payable prices above (e.g., $p = 50(f_i + 1)$) and below (e.g., $p = 50 f_i$) the wholesale price $\tilde{p}$ are used. This is an example of non-convergent to one price for one good under the competitive market.

In this example, the long-time customers have to pay a price higher than the marginal cost. How high would the price level be ? It depends on the price elasticity of the long-time customers and the number of them and also depends the lower price level set for the one-time shoppers which, in turn, depends on the price elasticity and the number of them. Figure 3.2 illustrates this case. The demand curve of the long-time customers is V_α, which implies a low price elasticity (the slope of the demand curve is steep). It implies that demand of the long-time customers would not lose (X_α) as much, therefore the deadweight loss would not be as large (pink triangle in Fig. 3.2), even if the price p_α is set above the wholesale (equilibrium) price $\tilde{p}$. The demand curve of the one-time shoppers V_β implies a high price elasticity (a flatter demand curve) and thus the deadweight loss would be very large if the price is set at p_α. On the other hand, if the price is set at p_β below the wholesale price $\tilde{p}$, the one-time shopper's demand (X_β) expands substantially. As is clear from the illustration in Fig. 3.2, it is better to allocate p_α for the long-time customers and p_β for the one-time shoppers. The market competition continues until the merchant's marginal profit reaches zero. To accomplish this, we can imagine that the merchant gains revenues by raising the price to $p_{\alpha,}$ and by losses from demand shrinkage, the net gain/loss from long-time customers is calculated. By the same token, as the merchant loses by reducing the price to p_β and gains from demand increases, the net loss/gain from one-time shoppers is calculated. These two-sided gains and losses will cancel out each other and reach zero net profit. However, because of price discontinuity, the payable price may not coincide with the price at which the marginal profit reaches zero from Eq. (3.8).

We assume that the demand function take a standard functional form,

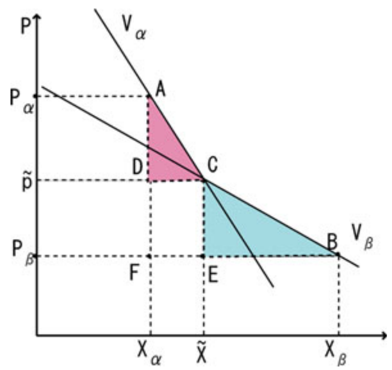

Fig. 3.2 Price setting under two demand curves

$$V_i = x_i = k_i p_i^{-\varepsilon_i} \tag{3.9}$$

where k_i is a parameter that determines the size of demand, and ε_i is the price elasticity of demand.

The Ramsey price corresponding to this demand function is defined as,

$$p_i = \frac{\varepsilon_i \tilde{p}}{\varepsilon_i - \lambda_i} \tag{3.10}$$

To solve (3.10) for λ_i,

$$\lambda_i = \frac{p_i - \tilde{p}}{p_i} \varepsilon_i i = \alpha, \beta \tag{3.11}$$

In general, $\frac{p_i - \tilde{p}}{p_i}$ is known as the markup rate.[17] This is equivalent to the ratio of infeasible payment and total payment,Z_i[18] as shown in Eq. (3.3). Inserting Z_i and rewriting Eq. (3.11),

$$\lambda_i = Z_i \varepsilon_i i = \alpha, \beta \tag{3.12}$$

Equation (3.12) implies that λ_i[19] is uniquely determined by Z_i andε_i. Furthermore, with payable price p_i as a multiple of 50 dinars, the wholesale price $\tilde{p}$, and price elasticity ε_i, λ_i is determined by Eq. (3.11). That is to say, by changing λ_i we can express any payable price that satisfies the Ramsey price. Here we divide consumers into two groups. If we could further divide them into more groups, we could assign the Ramsey prices respectively.[20] It is certainly efficient to introduce two prices p_α and $p_{\beta,}$ above and below $\tilde{p}$ the wholesale price (i.e., $p_\alpha > \tilde{p} > p_\beta$) in the sense that an increase in the consumer surplus is expected to exceed a reduction of the producer surplus under the two-price market, compared with the case in which the payable price is fixed at $p_i = 50(f_i + 1)$ and apply this price for all consumers. In other words, assuming many merchants sell the same goods and new merchants enter the market as far as the marginal profit remains positive, the merchant would not survive in the market competition if it applied the one good to one price.

We can observe the price-setting behavior of the merchant from a different perspective. Under the one good–two (many) prices mechanism, it is essential to

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[17] According to Iqbal (1997), in Islamic society, interest income is prohibited in commercial trading. As a result, most profits are generated by markups,

[18] Note that in Eq. (3.2), we restrict case $X_i = f Q_6 + g_i$.

[19] In general, the Ramsey rule assumes λ_i is constant for the same goods. But as we treat different prices for different consumers for the same goods, we assume $\lambda_\alpha \neq \lambda_\beta$.

[20] To set the price of individual goods as a multiple of 50 dinars is a sufficient condition for total payment (after aggregating several goods) becoming a multiple of 50 dinars but not a necessary condition. Given the possibility of purchasing a single good, all goods are priced as a multiples of 50 dinars. In fact, it was said that most goods in Iraq were priced in multiples of 50 dinars.

distinguish consumers with different demand functions. From our viewpoint, one of the most suitable verifying mechanisms is to use the bilateral (face to face) trade in the bazaar. In Arabic and Persian societies, the main trades take place in the bazaars, and the trading styles and divisions of labor are well defined.[21]

The advantage of bilateral trade in the bazaar is its ability to accumulate customer-specific information. Asymmetric information between the merchant and long-time customers would be substantially reduced by the repeated bilateral trades. In so doing, the merchant can set two (many) prices according to the types of consumers. This result reflects functioning in the bazaar as stated above. In short, the merchant cannot make profits one-sidedly in the bazaar; some consumers can purchase goods at prices lower than the wholesale price.

Another familiar retail trading system is the supermarket style. In this system, mass consumers buy "one good, one price" without any differentiation among different consumers. In order to make positive profits, the merchant (supermarket manager) must set prices at least, p $= 50(f_i + 1)$ for all consumers. This trade is profitable for the merchant, but consumers face the higher average price than that in the bazaar. In this trade, consumers are price takers regardless of demand amounts, there is no information feedback from consumers to the merchant (supermarket manager).[22]

In general, the merchant cannot capture the entire demand information of individual consumers, thus asymmetric information between them remains somehow. However, consumers can be classified according to the amount of consumption. In the literature of industrial organization, in general and in public utility pricing in particular, for example, a residential electricity tariff or telephone calls or mail services often use efficient pricing such that, given a regulated firm that must break even and which serves M markets, the efficient set of prices $p_\alpha, p_\beta, p_\gamma, \ldots p_M$ is that set which maximizes total surplus subject to the constraint that the firm earns zero profit (Brown and Sibley, 1986, p. 37) (see Fig. 3.3).[23]

In case of electricity use or telephone calls, the amount of consumption (number $\times$ time of calls) and firms and individuals are identified, the public utility firms can differentiate individuals and firms, even if specific individuals who use electricity or telephone services may not be known. In other words, it is justifiable to differentiate consumers according to amount of consumption if and only if the amount of consumption and types of consumers correspond one to one. However, in the case of general consumption goods, such a relationship does not hold. For example, if the types of consumers are categorized not by price elasticity but by the amount of consumption, the large-scale consumers would be provided the lower price. We can easily imagine that small-scale consumers or firms can collusively form a cartel (e.g., residents in a large condominium or firms using a high-rise office building) and

[21] Iwasaki (2004) reports detailed functioning and divisions of labor in the large-scale bazaar in Teheran, Iran. Similar trade systems are found in Istanbul(Turkey), Cairo (Egypt), and Bagdad (Iraq), among others.

[22] In principle, e-commerce tries to capture detailed information on individual customers by means of expending trading platforms that play an equivalent role of the bazaar.

[23] See Brown and Sibley (1986) and Shy (1995, Chap. 13).

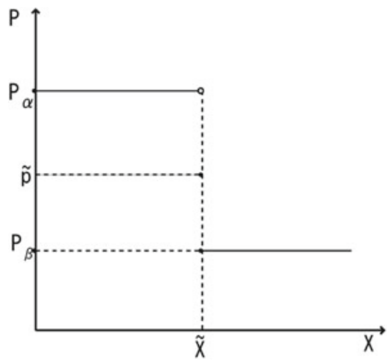

Fig. 3.3 Nonuniform price schedule

obtain goods and services at a discounted price. Without monitoring in person (e.g., bilateral trade in the bazaar), it is almost impossible to differentiate consumers by the amount of consumption in which time and places of individual consumption are not identified.

3.3.3 *Pricing Under Sales on Credit and Risks on Settlement*

As discussed above, it is possible to make an average payment price closer to the wholesale price (marginal cost) by pooling payment amounts and reducing the ratio of infeasible payment amount and total payment. However, if payment amounts are pooled indiscriminately, default risks at the time of settlement would increase as a result. That is, by pooling payments, distortion due to the limited denominations is eliminated to some extent; however, the merchant would certainly face higher risks. How can these two elements compromise each other?

In general, the merchant decides the timing of settlement according to the observable behavior of consumers, in other words, the length of credit is determined by the degree of default risk of consumers. In case of the one-time shopper, the merchant requires on-the-spot (real-time) payment. In case of long-time customers, for example, the other merchants in the same bazaar or the customers with stable income, the merchant can fix the time of settlement according to the merchant's payment schedule without a high default risk. Even if the customers come to the retail shop often, as long as the merchant judges the customers' income flows are not secure or stable, then he might ask for on-the-spot settlements. The merchant allows such a payment style according to creditworthiness (i.e., allows it from lower-risk consumers). He does not accept credit for risky individuals.[24]

[24] Iwasaki (2004) argues that in Iran, the producer and the wholesaler, the wholesaler and the retailer usually use a consignment sales format and they also use a few months' commercial bill rather than cash for settlement. In order to properly function, the sales on credit between the merchants and the customers and among the merchants, the long-time relationship between the merchants and the producers with consignment sales agreement is also very important. In a sense, the merchant plays

Suppose the average prices of a part of long-time customers are reduced by sales on credit to maintain the constraint in Eq. (3.8). The average prices of the rest of the long-time customers (e.g., salaried workers, elderly people, widows) must rise. In this circumstance, we may face "one good, three (more) prices",[25] namely, one-time shoppers pay a lower price than the wholesale price, then the long-time customers with stable income pay the second-lower price, and finally the customers with unstable income pay the highest price. It is a paradoxical result.[26]

Finally, let us consider the payment risks in society, rather than individual payment risks for individual goods—that is to say, the ratio between infeasible payment amounts and socially aggregate total payment for various goods with various prices. The socially infeasible payment ratio is given as follows,

$$W_i = \frac{\sum g_i}{\sum X_i} \tag{3.13}$$

For example, of all total payments between 1 and 1,000, the socially infeasible payment amounts consist of the numbers with the last two digits take 1–49.[27] To calculate this example, $\sum g_i = 24{,}500$, $\sum X_i = 500{,}500$, then $W_i = 0.04895$. The socially infeasible payment ratio is 4.9%. If we increase the total payment amount, this ratio will drop. This is not an example of aggregate small payments of the same goods to yield a large payment. We could interpret it to mean that individual small payments for different goods are aggregated to a large payment. With this method, the socially infeasible payment ratio can drop. However, in reality, this type of payment aggregation seems difficult to implement because usually commercial trades are decentralized by firms, retail shops, and merchants and it may not be feasible to aggregate individual payments socially in practice.

As we see, if a payment contains a remainder part, the merchant decides payment amounts by changing prices according to the customers' financial positions. This seemingly inefficient procedure prevents the merchant or the consumers from losing profits one-sidedly. This type of bilateral trade is allowed only to a limited extent. As the economy is modernized and expands its size, it is necessary to remove the payment and accounting obstacles in which the currency denomination system generates infeasible payment amounts.

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the role of intermediary, like a bank, as a financial intermediary. It is noteworthy that commercial bills and checks were an innovation of Islamic merchants in the tenth century. The English word "check" originally came from the Arabic word *cekk*.

[25] If the long-time customers know that the prices they face may differ according to creditworthiness or credit history, some of them may not be happy with this consignment sales format. From the customers' point of view, price differences between those who pay on-the-spot and those who pay on credit may not be observable, so it will not be a big problem.

[26] It may resemble the optimal consumption tax result in which the low price elasticity of demand for necessity goods such as food charges a higher tax rate and the high price elasticity of demand for luxury goods charges a lower rate.

[27] In case of the last two digits 51–99, as 50 dinara can be paid, the remaining amount would be 1–49, which is truly an infeasible amount.

3.4 Conclusion

The future of Iraq depends on how the government steadily constructs or reconstructs economic and social institutions that citizens will accept. Finance is no exception. The most important tasks are to maintain a credible central bank and, in turn, the central bank maintains the currency value and stability of the financial system. As long as achieving a stable currency value and keeping a low inflation rate, citizens will start saving and investing in the financial institutions and as a result, the financial market will induce further financial development. As the economy normalizes, Iraq will start exporting oil and importing various goods and services. The profits from oil would be invested abroad. In such a case, the government must face questions about how to introduce an acceptable foreign exchange law and how to maintain the foreign exchange system. It is an important policy question as to whether the government implements the exchange rate agreement with neighboring countries or the free-floating exchange system or the currency board system.

In this chapter, we have not discussed a broad financial market design as such. In a sense, the issue we discussed here is more profound and is highly relevant to the digital economy. At the moment, the modern theory of optimal pricing of goods and services uses the marginal cost and the price elasticity and assumes any price can be expressed in a set of currency denominations. In Iraq, however, this pricing method does not work because of limited denominations. As a practical reaction to this institutional obstacle, the merchants seem to use bilateral trade and prevent the market participants from losing profits one-sidedly. Nonetheless, the limited denominations prevent holding the "one good, one price" principle and cause many inconveniences in economic contracts that restrict payment feasibility greatly. In short, this currency system stands squarely in the way of the modernization of the Iraqi economy.

It may seem trivial to provide a 1 dinar denomination as the basic unit of accounting in their currency system in Iraq. As the production cost exceeds the face value at the moment, no one would dare to provide a 1 dinar denomination. As is discussed extensively in this chapter, a potential demand for small denominations would not be negligible.

As an aid for Iraq's reconstruction, the Japanese government can consider not only providing finance projects and their personnel, but also assisting in printing small-denomination notes such as 1 dinar, 5 dinar, and 10 dinar notes by the National Printing Bureau of Japan.[28] As the production cost exceeds the face value, there is no incentive to make counterfeits, so it is safe to use. As they are banknotes rather than coins, there is no risk of melting them and selling the materials. From the viewpoint of institutional complementarity, to improve the currency system and to make the commercial trading system more efficient, they will complement reconstruction of Iraqi society. It may not be a bad form of assistance, considering the next 20 or 30 years as our time horizon.

[28] We all know the British De La Rue is the private company printing Iraqi banknotes for decades. Printing small denominations for Iraq may not make economic sense from the private sector's viewpoint.

3.5 Appendix: Solution for an Indeterminate Equation and Its Application

According to Yamamoto (2003, p. 17) and Kitamura (1999, pp. 35–36), a set of integers $(x_1, x_2, x_3, x_4, \ldots .x_n)$ is a solution for the algebra equation with integer coefficients $f(Q_1, Q_2, Q_3, \ldots .Q_n)$ where $Q_1, Q_2, Q_3, \ldots Q_n$ are variables. This type of algebra equation is called an indeterminate equation. Finding all solutions for integer coefficients is described as solving an indeterminate equation.

Theorem 3.1 Suppose d is the greatest common divisor (gcd) for integers $Q_1 > Q_2 > Q_3 > Q_4 > \ldots, > Q_n$, then an indeterminate equation, $x_1Q_1 + x_2Q_2 + x_3Q_3 + x_4Q_4 + \ldots + x_nQ_n = kd$ having a solution. It is equivalent to finding d as the greatest common divisor for integers $Q_1, Q_2, Q_3, Q_4, \ldots, Q_n$.

Proof 3.1 It is obvious that an indeterminate equation kd has a solution; then the greatest common divisor is d. On the other hand, if d is the greatest common divisor for kd, given a set of solution for an indeterminate equation, $x'_1Q_1 + x'_2Q_2 + x'_3Q_3 + x'_4Q_4 + \ldots . + x'_nQ_n = d$, then k times the solution $(kx'_1, kx'_2, kx'_3, \ldots k'x_n)$ is also a solution. (Q.E.D.)

The general solution for an indeterminate equation is given as below. First, two largest variables, Q_1 and Q_2. Suppose the greatest common divisor of Q_1 and Q_2 is defined as $d_1(Q_1,Q_2)$, an indeterminate equation $x_1Q_1 = x_2Q_2 = md_1 = kd\text{-}x_3Q_3\text{-}x_4Q_4\text{-}\ldots\text{-}x_nQ_n$ (where m is an integer) has a solution $(\widehat{x_1}, \widehat{x_2})$, the general solution can be defined as such,

$$x_1 = \widehat{x_1} + Q_2t \tag{3.14}$$

$$x_2 = \widehat{x_2} + Q_1t \text{where t} = 0, \pm 1, \pm 2 \tag{3.15}$$

As $x_1Q_1 = x_2Q_2 = md_{1,}$ this indeterminate equation can be rewritten as:
$md_1 + x_3Q_{3+}x_4Q_{4+}\ldots + x_nQ_n = kd.$

Second, suppose the greatest common divisor of d_1 and Q_3 is $d_2(d_1, Q_3)$,
$md_1 + x_3Q_3 = sd2 = kd\text{-}x_4Q_4 - \ldots - x_nQ_n$ (where s is an integer) has a solution, the general solution can be defined as such,

$$m = \hat{m} + Q_3t \tag{3.16}$$

$$x_3 = \widehat{x_3} - d_1t \text{where t} = 0, \pm 1, \pm 2 \tag{3.17}$$

Third, repeat the same procedures and finally reach the greatest common divisor of $d_{n\text{-}2,}$ and Q_n is d, the indeterminate equation $zd_{n\text{-}2} + x_nQ_n = kd$ has the general solution such that

$$z = \hat{z} + Q_nt \tag{3.18}$$

$$x_n = \widehat{x_n} - d_{n-2}t \text{where t} = 0,\ \pm 1,\ \pm 2 \tag{3.19}$$

We have obtained the general solution for $x_1, x_2, x_3, x_4, \ldots x_n$..

If we take $Q_1, Q_2, Q_3, Q_4, \ldots. Q_n$ as currency denominations and *kd* as the payment amount, it is the same as figuring out how to pay the amount by means (integer) of different denominations. Suppose we have six denominations, that is, $Q_1 = 25{,}000$, $Q_2 = 10{,}000$, $Q_3 = 5{,}000$, $Q_4 = 1{,}000$, $Q_5 = 250$, and $Q_6 = 50$. The greatest common divisor in this currency system is $\gcd(Q_i) = 50$.

Equation (3.2) is rewritten as,

$$X_i - g_i = aQ_1 + bQ_2 + cQ_3 + dQ_4 + eQ_5 + fQ_6$$

$$= \gcd(Q_6) \times \{500a + 200b + 100c + 20d + 5e + f\} \tag{3.20}$$

The minimum positive value for X_i is obtained when a = b = c = d = e = 0, and f = 1, $X_i - g_i = \gcd(Q_6) \times 1 = 50$. This result can be interpreted to mean that economic value X_i is converted into payable monetary value $X_i - g_i$ by discounting g_i. From our daily experience, there are many ways to pay a certain amount by currency denominations, allowing changes.

Let us think of the 6-element first-order indeterminate equation,

$$X_i - g_i = 50f_i + 250e_i + 1000d_i + 5000c_i + 10000b_i + 25000a_i \tag{3.21}$$

Payable monetary value $X_i - g_i$ is restricted to the case of multiples of 50, i.e., $50n$. For simplicity, we ignore the case of making changes.[29] How many ways can we pay, given all available currency denominations?[30]

Let us consider the small denominations first, contrary to the general solution for indeterminate equations:

(1) To pay 250 *m* dinar with 50 and 250 dinar notes[31] (i.e., two denominations).
$250\ m = 50f_i + 250e_i$

$$f_i = 5m - 5e_i = 5(m - e_i) \tag{3.22}$$

Define $N_2(m)$ as the number of solutions (0 and positive integers) for *e* and *f* in the indeterminate equation (A9). As f_i is a multiple of 5, put $f_i = 5k$ and

[29] Allowing changes implies negative integer solutions in the indeterminate equation. The number of solutions increase as a result, but mathematical fundamentals remain the same.

[30] This problem is basically the same as discussed in Yamamoto (2003, p. 22, 354–355). See also the original contribution in this problem by Polya (1956) and its modern treatment by Graham et al. (1994, Chap. 7).

[31] The payable amount is set at 250 m because this amount can be paid either by 250 dinar notes or multiples of 50 dinar notes ($250mk \times 50$n). In the following, the payable amount is considered the multiple of the maximum denomination.

then $e_i = m - k$. From $e_i \geq 0$, $f_i \geq 0$, $0 \leq k \leq m$. If k is fixed, then $f_i and e_i$ are automatically determined. The number of solutions in this case is $m + 1$.

$$N_2(m) = m + 1 \tag{3.23}$$

(2) To pay 1,000 m dinars with 50, 250, and 1,000 dinar notes (i.e., three denominations).

$1000\ \mathrm{m} = 50f_i + 250e_i + 1,000d_i$

$$f_i + 5e_i = 20(m - d_i) = 20k \tag{3.24}$$

Define $N_3(m)$ as the number of solutions, $d_i = m - k$. The same as the two-denomination case (1) above, $0 \leq k \leq m$. For this amount (1,000 m) in the case of two denominations, the number of solutions are $N_2(4\,k)$.

$$N_3(m) = \sum_{k=0}^{m} N_2(4k) = \sum_{k=0}^{m} (4k + 1) = (2m + 1)(m + 1) \tag{3.25}$$

(3) To pay 5,000 m dinars with 50, 250, 1000 and 5,000 dinar notes (i.e., four denominations),

$$5000m = 50f_i + 250e_i + 1000d_i + 5000c_i$$

$$f_i + 5e_i + 20d_i = 100k \tag{3.26}$$

From (3.26), $c_i = m - k$. The same logic follows $0 \leq k \leq m$. For this amount (5,000 m) in case of three denominations, the number of solutions is $N_3(5\,k)$

$$\begin{aligned} N_4(m) &= \sum_{k=0}^{m} N_3(5k) = \sum_{k=0}^{m} \{(10k + 1)(5k + 1)\} \\ &= 50\sum_{k=0}^{m} k^2 + 15\sum_{k=0}^{m} k + (m + 1) \\ &= \frac{1}{6}(m + 1)\left(100m^2 + 95m + 6\right) \end{aligned} \tag{3.27}$$

(4) To pay 10,000 dinars with 50, 250, 1,000, 5,000, 10,000 dinar notes (i.e., 5 denominations).

$10000\, m = 50f_i + 250e_i + 1,000d_i + 5,000c_i + 10,000b_i$

$$f_i + 5e_i + 20d_i + 100c_i = 200k \tag{3.28}$$

From (3.28), $b_i = m - k$. The same logic follows, $0 \leq k \leq m$. For this amount (10,000 m) in case of three denominations, the number of solutions is

$N_4(2\,k)$.

$$N_5(m) = \sum_{k=0}^{m} N_4(2k) = \sum_{k=0}^{m} \frac{1}{6}\left(800k^3 + 780k^2 + 202k + 6\right)$$
$$= \frac{400}{3}\sum_{k=0}^{m} k^3 + 130\sum_{k=0}^{m} k^2 + \frac{101}{3}\sum_{k=0}^{m} k + (m+1)$$
$$= \frac{1}{6}(m+1)\left(200m^3 + 460m^2 + 231m + 6\right) \tag{3.29}$$

(5) To pay 25,000 dinars with 50, 250, 1,000, 5,000, 10,000, and 25,000 dinar notes (i.e., 6 denominations).

$25{,}000\, m = 50f_i + 250e_i + 1,000d_i + 5,000c_i + 10,000b_i + 25,000a_i$

$$f_i + 5e_i + 20d_i + 100c_i + 200b_i = 500k \tag{3.30}$$

From (3.30), $a_i = m - k$. The same logic follows, $0 \le k \le m$. For this amount (25,000 m) in case of three denominations, the number of solutions is $N_5(\frac{5}{2}\,k)$.

$$N_6(m) = \sum_{k=0}^{m} N_5\left(\frac{5}{2}k\right) = \sum_{k=0}^{m} \frac{1}{6}\left(\frac{5}{2}k + 1\right)\{200(\frac{5}{2}k)^3 + 460(\frac{5}{2}k)^2$$
$$+231\left(\frac{5}{2}k\right) + 6\}$$
$$= \frac{400}{3}\sum_{k=0}^{m} k^3 + 130\sum_{k=0}^{m} k^2 + \frac{101}{3}\sum_{k=0}^{m} k + (m+1)$$
$$= \frac{1}{48}(m+1)\left(125000m^4 + 39375m^3 + 34225m^2 + 6045m + 48\right) \tag{3.31}$$

When $m = 1$, $N_6(1) = 3841$, $m = 2$, $N_6(2) = 41{,}502$.

In case of six denominations in Japan (1, 5, 10, 50, 100, 500 yen coins), to pay $500n$, we have a similar solution such that

$$N_6(n) = \frac{1}{6}(n+1)\left(12500n^4 + 29372n^3 + 15800n^2 - 195n + 6\right) \tag{3.32}$$

When n $= 1$, $N_6(1) = 19,162$, $n = 2$, $N_6(2) = 248{,}908$. With the same six denominations, although denomination units are different between Iraq and Japan, there is the same face-number 500—in the case of Iraq, $N_2(2) = 3$, while in Japan it is $N_6(1) = 19,162$. To pay 25,000, in Japan with many small denominations, $n = 50$, $N_6(50) = 695{,}609{,}104{,}676$. In Iraq it is $m = 1$, $N_6(1) = 3841$. It is obvious that with many small denominations, Japan has overwhelmingly many ways to pay the same number (amount).

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Chapter 4
Diffusion of Electronic Money and Choice of Payment Methods

4.1 Introduction

Electronic money has been around for about 10 years,[1] but it did not become as popular as initially hoped in the 1990s. However, in 2000, Suica by East Japan Railway Company and Edy by BitWallet, Inc. began to spread as more common electronic money, and electronic money began to be used in earnest. The purpose of this chapter is to discuss, from both theoretical and empirical perspectives, the mechanisms and systems necessary for the further diffusion of the new e-money that began to emerge in the beginning of 2000s, drawing on the experiences of the 1990s.

The structure of this chapter is as follows. In Sect. 4.2, we survey the distribution of e-money, focusing on Suica and Edy, which have recently been expanding rapidly. Section 4.3 discusses the mechanisms for promoting e-money circulation from the perspective of e-money's transaction cost advantage, technological future, and scalability. Section 4.4 theoretically analyzes how e-money will be selected from multiple payment methods such as cash and credit cards, based on the actual situation up to that point. Here, we show that the usage ranges of e-money, cash, and credit cards are determined by the differences in their respective transaction costs. We also show that in practice, the use of e-money depends not only on the cost difference but also on the number of consumers per shop. In Sect. 4.5, I examine the implications of e-money for monetary policy by examining how the cash currency issued by the central bank would eventually increase in terms of monetary aggregates under the presence of e-money. I also show that the setting of the deposit reserve ratio for electroncic money is important in this process. Section 4.6 provides a brief summary of the overall results.

[1] Note that this chapter was originally written in July 2005.

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4.2 The Actual State of Distribution of Electronic Money

Today, Suica and Edy have become popular as mediums that serve as prepaid electronic wallets (e-money). Of course, their scale is still small, but with the entry of major transportation-related companies such as JR, JAL (Japan Airlines), and ANA (All Nippon Airways), their widespread use is gaining momentum.

The electronic money in circulation in Japan is not limited to Edy and Suica, but since these are the two that are spreading on a national scale, we will focus on them.[2]

As of the end of April 2005, 10.2 million Edy cards had been issued by BitWallet, which can be used at1,400 "am/pm" convenience stores and 20,000 other stores nationwide, including department stores, pharmacies, bookstores, hotels, airports and amusement facilities.[3] Edy cards can be purchased for 315 yen at convenience stores and other locations, and up to 50,000 yen can be deposited at terminals at partner stores. There are also more than 500 Edy-enabled websites, making it easier to shop online. Member stores are also offering discounts to encourage the use of Edy. Among other things, the alliance with ANA Mileage Club allows users to exchange 10,000 miles for 10,000 yen worth of Edy, earning one mile for every 200 yen spent using Edy, or one mile for every 100 yen spent with credit cards such as VISA and Mastercard. You can earn one mile for every 100 yen you spend. The same concept can be applied to Mizuho Mileage Club. The other mainstay of widespread use, cooperation with mobile phones, is also under way. Edy is included in NTT DoCoMo's Osaifu-Keitai (mobile wallet), and is set to be included in au and Vodafone from autumn 2005.[4]

Suica, on the other hand, originated from the contactless payment system (automatic ticket gate) at stations introduced by JR East, and electronic money functions were added in March 2004. A total of 12.01 million Suica cards had been issued as of the end of April 2005, and more than 6.85 million shopping-enabled Suica cards have been issued. Suica cards are sold from vending machines at JR stations for 2,000 yen each (including a 500 yen deposit), with a maximum deposit of 20,000 yen.

As of April 2005, the number of stores where Suica can be used is said to have exceeded 1,000 at 802 stations. From 2005, Suica will be available for payment at 2,800 convenience stores, including New Days (300 stores) and FamilyMart stores in the Tokyo metropolitan area and Sendai area. It is also said that Suica will be available on private railways and buses in the Kanto area in 2006. However, compared to Edy, its use outside of train stations is limited and the number of stores where it can be used is still small.

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[2] The following information is based on "Edy versus Suica: Using Electronic Money", Nihon Keizai Shimbun, May 22, 2005.

[3] The number of Edy cards issued doubled from 5.1 million by the end of July 2004 to 10.2 million by the end of April 2005, nine months later. Judging from the pattern of the spread of goods in the past, this may be regarded as the beginning of a full-scale diffusion period.

[4] Vodafone was merged with Softbank in 2006 and stopped its operation then in Japan.

As a benefit of using Suica, when you charge Suica on the View Card, a credit card issued by East Japan Railway Company, you can earn three times the amount of Thanks Points that you normally earn based on the amount you spend on your credit card. While Edy is tied up with ANA, Suica is tied up with JAL, and 10,000 miles can be exchanged for 10,000 yen worth of Suica as JAL mileage points (with a limit of 20,000 miles per year). The company also has a partnership with Mizuho Mileage Club. Although it is behind Edy in terms of mobile phone integration, it will be included in DoCoMo's Osaifu-Keitai mobile phone system as Mobile Suica from January 2006.

Both Edy and Suica are basically highly anonymous, but this also means that they can be used by a third party if they are lost. It is thought that the upper limit on the amount of money that can be loaded is set with this risk of loss in mind. However, in the case of commuter pass-type Suica, the user's name is registered, and the use of the lost Suica is stopped and the balance is reissued. Osaifu-Keitai (mobile wallet) also has a function to lock the mobile phone and prevent a third party from using it if it is registered in advance. In this way, it has become possible to maintain anonymity regarding the use of e-money and, to some extent, reduce the risk of loss. However, there is still a risk of losing the e-money if the card containing the e-money is physically damaged or submerged in water.

4.3 Mechanisms to Promote the Distribution of Electronic Money

In general, when a new product is introduced, the extent to which the product is accepted in the market is a matter of substitutability with existing products. In the case of electronic money, cash, prepaid cards, debit cards, and credit cards are considered to be substitutes. The question is how e-money can replace cash and various types of cards that are already in circulation.

The difference between e-money and a credit card is that you can settle your payment immediately. It can be used by people under 18 years old who cannot have a credit card. The difference with debit cards is that they do not require identification number and are faster to settle, but there is a limit to the amount that can be charged. E-money is designed to be used for small payments, and is intended to be used for that purpose. While prepaid cards are generally disposable, e-money can be recharged and used over and over again. Also, since e-money uses IC cards, it can record a large amount of data. This makes it possible to accumulate and use data such as points attached to various types of consumption and personal consumption history.

From the merchant's point of view, this reduces cash-holding balances, which reduces handling costs and reduces the risk of theft and other holdings. It is known that settlement during busy times can be shortened by about 25%. Another advantage is that while there is a risk of receiving counterfeit currency in cash settlements, there is no counterfeiting yet with electronic money, and it is safer than cash.

If these differences were considered sufficiently differentiating, e-money would be accepted as a means of payment and settlement, as it is for cash and various cards. But the advantages mentioned above were already there from the beginning of the first introduction of e-money in the 1980s and 1990s, and at that time it was not distributed nor was it promoted, thus other reasons must explain its success since the beginning of the year 2000.

According to BitWallet, (1) electronic money has become contactless, speeding up the exchange of information and making it possible to integrate it into mobile phones and other devices, as well as making it possible to use payment terminals at low cost. (2) By collaborating with transportation-related companies that have networks, the use of e-money has expanded from regional money to national money, which in turn has led to the participation of businesses, an increase in customers, and a reduction in costs. (3) The development of infrastructure (e.g., JR ticket gate systems) to accommodate the use of e-money.

Although it is beyond the scope of this chapter to analyze the technical aspects of (1) and (3), it can be said that the infrastructure for the distribution of e-money was promoted in cooperation with other network-related businesses. (2) is discussed below, but it can be assumed that cooperation with transportation-related companies was a major factor in transforming what had been a closed regional e-money system into a nationwide e-money system.[5]

Until now, cash recharging could be done easily at stations with Suica, but Edy was not so widespread, although recharging terminals were installed at convenience stores. There was also the problem of the cost of recharging using a PC, which required a separate IC card reader/writer. When e-money functions were installed on mobile phones, recharging became possible via i-mode, eliminating the need to install a recharge terminal in the first place and making it possible to recharge anytime, anywhere. Users, e-money issuers, and merchants alike will benefit greatly from this feature, as they can download various applications from the i-appli of i-mode, so there is no need to have them pre-installed on their mobile phones, and only the applications they use need to be loaded.

It is envisaged that the mainstream form of electronic money distribution in the future will be through mobile phones, and that electronic money will be exchanged between individuals, rather than being a mere means of payment, and that electronic money will be distributed in a form similar to current currency. In addition, by linking to mobile phones, it will be possible to purchase JR seats or concert tickets by making a reservation over the phone, and enter the venue using the mobile phone instead of the ticket as it is. In addition, if a contract is made to set a certain minimum amount of electronic money to be held, it can be automatically recharged at automatic ticket gates or through digital communication. In this way, the cost of recharging would be dramatically reduced.

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[5] JR East plans to offer Suica as a business with high future potential, using the technology for services such as building access control and personal authentication for PCs, and is not simply incorporating electronic money into its existing network business.

I think it is safe to say that we are finally coming to the aspect of the use of electronic money on the Internet that was thought to be possible when electronic money was first introduced, and as a result, electronic money is being used more and more.

On the basis of these observations, let us theoretically derive the conditions for e-money to replace cash and other payment instruments.

4.4 The Problem of Choosing Between Multiple Payment Methods

According to Iwamura (1996), the segregation of settlement instruments can be represented as shown in Fig. 4.1.

That is, settlements are for large amounts of money exceeding one billion yen, which include both inter-company settlements and inter-governmental transfers such as development assistance. Cash is rarely used for such settlements, but rather checks are exchanged between financial institutions or, today, almost exclusively, electronic payments between financial institutions (large electronic fund transfers, or EFTs). Smaller settlements, ranging from tens of thousands of yen to hundreds of millions of yen, are now mostly made by electronic fund transfer (small transfer EFTs). Smaller transactions, from a few thousand yen to tens of thousands of yen, are settled in

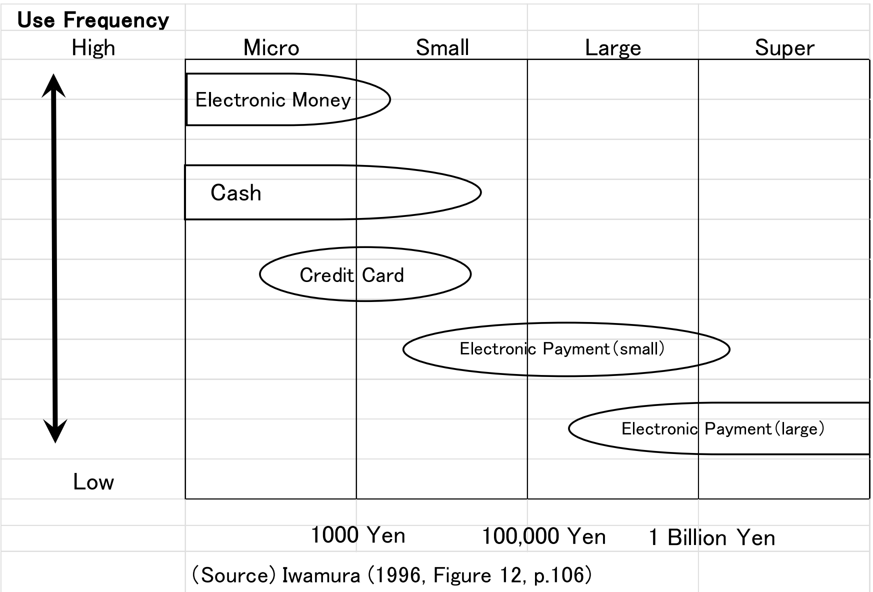

Fig. 4.1 Conceptual distribution of payment methods

cash or by credit card. Cash is legal tender and is accepted by all people, but credit cards are accepted only by a limited number of merchants. However, credit cards are convenient when traveling abroad because they allow people to make purchases of a certain amount of money without having to carry cash. Electronic money, which is the subject of this chapter's analysis, is generally expected to be used for very small payments, such as substituting for cash, especially small denominations. Looking at Fig. 4.1 from another perspective, it can be interpreted as follows. Settlements of tens of thousands of yen or more are already made using electronic media, such as credit cards and electronic payments, not by using cash, but by transferring information. This means that the use of cash is finally being limited by the introduction of electronic payment methods for very small settlements, which had been the last area of use for cash.

The problem of choosing multiple payment instruments began with the transaction cost currency demand model between deposits and cash of Baumol (1952) and Tobin (1956), and the problem of choosing multiple payment instruments including checks, credit cards, and other media was first discussed by Santomero (1979) and Whitesell (1989, 1992) and others, and was formulated as a general payment instrument selection problem in Santomero and Seater (1996). Although not multiple means of payment, Jovanovic (1982), Romer (1986), and Prescott (1987) formulated the Baumol–Tobin transaction cost currency demand function in the framework of general equilibrium theory.

Building on the accumulation of these studies, Shy and Tarkka (1998, 2002) present a convincing argument for the use of electronic money as a means of payment versus traditional payment methods such as cash, credit cards, and checks through a comparison of various costs, including transaction costs. The following is a summary of the discussion. In what follows, I will introduce the arguments of Shy and Tarkka (1998, 2002) and examine the conditions for and the scope of the use of electronic money. Electronic payments and payments by check, which appear in Fig. 4.1, are not considered in the following model because they are large in scale and cannot be substituted for electronic money.

4.4.1 Multiple Payment Models

We consider three types of payment instruments: electronic money (e-money), cash, and credit cards (abbreviated as "cards" in the following). We assume that there are four economic agents: (1) consumers or purchasers, (2) shops or merchants, (3) electronic money issuers, and (4) credit card issuers.

Let p ($p > 0$) be the value (price) paid in a transaction. Each shop is distributed according to the average transaction size p, which is called a shop of type p. The density function of this distribution of type p stores is denoted by m(p). This represents the number of shops of type p. Similarly for consumers, consumers with average price paid p are called type p consumers, and their density distribution is denoted by b(p).

We make the following assumptions about the distribution of merchants and consumers.

Assumption (1) b(p) and m(p) are differentiable continuous functions, and b(p) $\geq$ m(p) $\geq$ 0 for all p.

Assumption (2) b(p) is a decreasing function of p. The number of consumers according to the payment scale decreases with the amount.

Assumption (3) m(p) is a decreasing function of p. Shops based on the size of the transaction decrease with the settlement amount.

Assumption (4) The number of consumers per transaction per merchant decreases with the transaction value.

$$\frac{\partial\left[\frac{b(p)}{m(p)}\right]}{\partial p} < 0 \tag{4.1}$$

The assumption is that the number of customers of small retailers will be larger than the number of customers of large retailers.

Assumption (5) The consumer's density function b(p) is independent of the transaction costs of the payment instrument.

The assumption is that transaction costs affect the choice of payment instruments, but that transaction costs do not affect the sale or purchase of goods and services.

A detailed breakdown of the transaction costs for each economic agent is summarized in Table 4.1. The time cost T falls on the shopkeeper and the consumer. This is the cost of handling cash, such as calculation time and authentication cost. The theft and loss cost (λ) is incurred by the merchant, the consumer, and the e-money issuer. In the case of credit cards, theft insurance is included in the annual fee and is not a cost to the issuing entity. The cost of lost interest opportunity (i) is the cost of losing interest income by holding the money in cash. Here, the difference in holding period (v) is added to the interest opportunity cost in the case of a shop, a consumer, and an e-money issuer. For e-money, there is a technical breakage cost (γ) in the sense that if the magnetic data part is physically destroyed, it cannot be used. For credit card issuers, the authentication cost (V^C) is the only cost. The authentication cost does not depend on the transaction amount.

Electronic money issuers and credit card issuers charge merchants an annual membership fee (franchise fee f_0) and a transaction-based fee (divided into a fixed portion f_1 and a pay-as-you-go portion f_2) for using their cards.[6] In addition, electronic money and credit cards are subject to a communication equipment investment cost (E) for electronic payments.

The comparison of the various costs mentioned above by each economic entity will determine the extent of the use of payment instruments. For the consumer, using a credit card is the most cost-saving. However, merchants will only accept credit

[6] Although consumers may also be charged an annual fee for using the card, we ignore it here in comparison to the amount charged to merchants. And in fact, there are many cases where credit cards with no annual fee or electronic money are incorporated into credit cards so that no annual fee is charged for electronic money.

Table 4.1 Transaction costs in the payment system

	Cash transaction costs	Theft and loss costs (probability)[(1)]	Interest loss opportunity costs (interest rate)[(2)]	Technical damage costs	Authentification costs	Card user annual fee[(3)]	Card transaction fee (flat)	Card transation fee (Pay per use)	Payment terminal equipment instalation costs
Merchants	T^M	λ^M	i	0	0	$f_0{}^E$	$f_1{}^E$	$f_2{}^E$	E^E
Buyers/Consumers	T^B	λ^B	vi	0	0	$f_0{}^C$	$f_1{}^C$	$f_2{}^C$	E^C
E-money Issuers	0	λ^B	vi	γ^B	0				
Credit card Issuers[(4)]	0	0	0	0	V^C				

Note (1) We assume that $0 \leq \lambda \leq 1$.
Note (2) v is the relative rength of cash houlding period, compared with the merchants.
Note (3) Cards include both Electoronic cards (denotes E) and Credit cards (denotes C).
Note (4) Credit cards use the post paid system, there would be no opprtunity costs in interest rates. Both theft and loss costs and technical damage costs are covered by insurance (a part of annual fee), so that credit card issuers do not bear these costs.

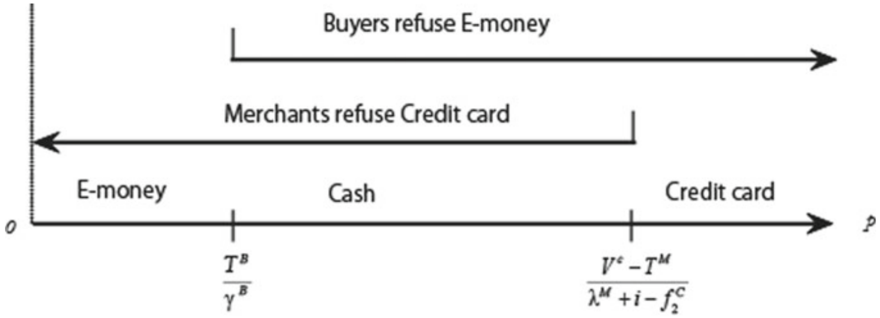

Fig. 4.2 Equilibrium boundary of payment methods. *Source* Shy (2001), Fig. 8.7, p. 210

cards if the transaction costs are lower for credit cards than for cash. This condition can be expressed as follows.

$$T^M + (\lambda^M + i)p > f_1^C + f_2^C p \text{ or } p > \frac{V^C - T^M}{\lambda^M + i - f_2^C} \tag{4.2}$$

With $f_0^C = 0, \ f_1^C = V^C$ we now assume[7] that if the transaction value p exceeds the lower bound given by (4.2), then credit card use outperforms other payment methods.

Next, we seek the extent to which e-money dominates. Merchants are more willing to use e-money than cash if there are no annual fees or transaction fees for e-money. The problem is that the boundaries of use are determined by the extent to which consumers are less willing to pay in cash than they are to pay in e-money at lower transaction costs.

$$T^B + (\lambda^B + vi)p < (\lambda^B + \gamma^B + vi)p \text{ or } p > \frac{T^B}{\gamma^B} \tag{4.3}$$

The conditions for the existence of a price range dominated by cash from (4.2) and (4.3) are as follows.

$$\frac{T^B}{\gamma^B} < \frac{V^C - T^M}{\lambda^M + i - f_2^C} \tag{4.4}$$

The above results are summarized in Fig. 4.2. The classification of payment methods here is based on optimal boundaries. This result is consistent with the concept of the distinction of payment methods shown in Fig. 4.1.

[7] If credit cards were in a competitive equilibrium, if the cost of credit card authorization could be covered by fee income from merchants, the rest of the annual fee for card use and the pay-as-you-go portion of the handling volume would be waived.

The following additional results are also obtained (Shy & Tarkka, 1998, Proposition 2).

Additional Result (1) A necessary condition for cash to remain is that the technical breakage cost of e-money is positive ($\gamma^B > 0$).

Additional Result (2) A necessary condition for cash not to be eliminated by credit cards is that the authentication cost of credit cards is higher than the cash handling time cost ($V^C > T^M$).

So far, the optimal boundary between e-money, cash, and credit cards has been obtained by calculating the cost of each economic agent. However, this does not necessarily coincide with the socially optimal boundary. That is, the region where e-money is socially preferable to cash is when the total transaction cost of both merchants and consumers is lower for e-money than for cash.

$$(\lambda^B + \gamma^B)p \leq T^B + T^M + (\lambda^B + \lambda^M)p \ or \ p \leq \frac{T^B + T^M}{\gamma^B - \lambda^M} \tag{4.5}$$

Comparing this socially optimal boundary with the boundary in (4.3), if the relationship is as follows, it means that e-money is only underused in terms of the social optimum.[8]

$$\frac{T^B}{\gamma^B} < \frac{T^B + T^M}{\gamma^B - \lambda^M} \tag{4.6}$$

Similarly, the area where credit cards are socially preferred to cash is when cash is higher than credit cards in terms of total transaction costs for both merchants and consumers.

$$V^C < T^B + T^M + (\lambda^B + \lambda^M)p \ or \ p > \frac{V^C - (T^B + T^M)}{\lambda^B + \lambda^M} \tag{4.7}$$

Comparing this socially optimal boundary with the boundary in (4.2), it means that the credit card is only underused in terms of the social optimum if the relationship is as follows.

$$\frac{V^C - T^M}{\lambda^M + i - f_2^C} > \frac{V^C - T^B - T^M}{\lambda^B + \lambda^M} \tag{4.8}$$

These results imply that e-money and credit cards are only underused in terms of the social optimum, while cash is overused in terms of the social optimum. This can be thought of as a kind of market failure, but as Fig. 4.3 shows, with respect to e-money, this is ultimately because the area of lower transaction costs is lower than the social optimum level when consumers pay with cash, and this is happening because the technological breakage cost of e-money is positive ($\gamma^B > 0$). If there is

[8] Since both λ^M and T^M are positive, the sign cannot be reversed and there is no possibility that e-money is overused from a social point of view.

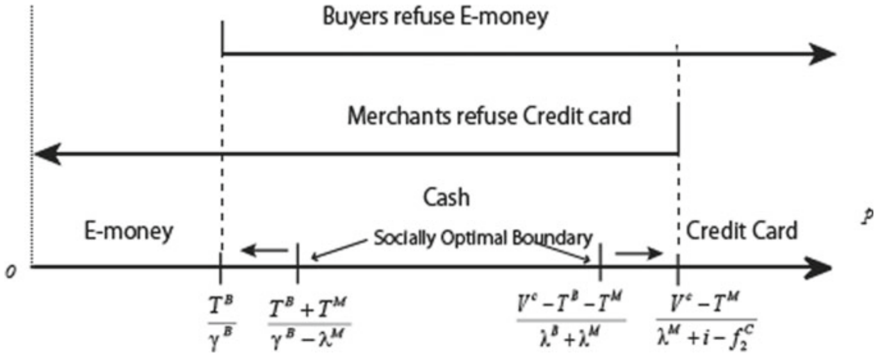

Fig. 4.3 Discrepancy between transaction-cost-based boundary and socially optimal boundary

technological progress and the technological breakage cost of e-money declines, the area in which cash is used is expected to shrink.

As for credit cards, in areas where the cost of credit card transactions is higher than that of cash, the level of credit card acceptance is higher than the socially optimal boundary, resulting in underuse of credit cards. As for credit cards, if the cost of authentication decreases, the credit card usage area will increase.

4.4.2 Competitive Conditions in the Market

So far, the boundaries of payment instruments have been determined basically only by comparing transaction costs. In the following, we consider the case of an oligopolistic market with a small number of credit card and e-money issuers, the case of a competitive market with a large number of issuers, and the case of a variable number of consumers based on the amount of transactions per shop.

The conclusion reached by Shy and Tarkka (1998) was that changes in the market structure would change who bears the burden of annual membership fees (connection and affiliation fees) and payment and communication equipment investment costs associated with card use. The following section presents the argument.

If the e-money issuer is an oligopoly, then the e-money issuer can collect all the surplus from the merchants. However, if the number of customers is small, the e-money issuer may not be able to collect any surplus. In this case, the e-money issuer will waive the annual card usage fee (connection fee) only for those merchants for whom the following equation holds ($f_0^E = 0$).

$$\left[f_1^E + f_2^E p\right]\frac{b(p)}{m(p)} = \left[T^M + \lambda^M p\right]\frac{b(p)}{m(p)} \geq E^E \tag{4.9}$$

If a shop cannot satisfy this equation, it will either not be allowed to connect to e-money payments or will be required to connect for a fee. Thus, whether a shop is excluded from the e-money payment connection depends on the distribution of $b(p)$ and $m(p)$.

In the area where electronic money is used, $(0, \overline{p}]$, the maximum value of $\overline{p}$, is determined to be the minimum value that satisfies Eqs. (4.9) and (4.3). In other words, $\overline{p}$ is determined so that the following equation holds.

$$\frac{b(\overline{p})}{m(\overline{p})} = \frac{E^E}{T^M + \lambda^M \overline{p}} \tag{4.10}$$

If e-money issuers are in competition, the annual fee for e-money card usage will be set to equal the cost of payment and communication equipment investment and will be borne by merchants. No other transaction fees are required. This means $f_0^E = E^E, \quad f_1^E = f_2^E = 0$ that In this case, too, a shop will accept e-money only if the relationship in (4.9) is satisfied.

Shy and Tarkka's (1998) argument here is that whether the card issuer or the merchant bears the burden of annual fees and transaction fees for using the card indicates the state of competition in the e-money card market. An intuitive explanation for this result can be given as follows. The oligopolistic e-money issuers set their transaction fees to be slightly below the merchants' cash transaction costs to maximize their surpluses, so they cannot afford to make the merchants pay annual fees, and the e-money issuers are forced to pay the annual fees. If merchants were required to pay an annual membership fee, the transaction costs of e-money would exceed those of cash, and merchants would withdraw from the use of e-money. On the other hand, competitive e-money issuers cannot set their transaction fees so as to recover all of the merchant's surplus, so the merchant will be left with some surplus, and as a result, the annual membership fee (connection fee) will be borne by the merchant.

Equation (4.10) implies that the e-money usage area is determined by the relative density of consumers and shops and the transaction cost ratio of e-money and cash. In the following, we show how the e-money usage area is divided into the e-money usage area and the cash usage area according to the $b(p)/m(p)$ curve and the shape of the $E^E/(T^M + \lambda^M p)$ curve.

In Fig. 4.4, the $b(p)/m(p)$ curve is a monotonically decreasing function, and at the point of intersection with the $E^E/(T^M + \lambda^M p)$ curve, the area is divided into the e-money use area and the cash use area. In Fig. 4.5, the $b(p)/m(p)$ curve has a U-shape, so it intersects the $E^E/(T^M + \lambda^M p)$ curve twice, and the pattern is that it changes from the e-money use area to the cash use area, then to the e-money use area again, and then back to the cash use area. This is a theoretical possibility, but it is difficult to imagine a situation in which the usage area switches in this way in reality. In Fig. 4.6, the $b(p)/m(p)$ curve is consistently lower than the $E^E/(T^M + \lambda^M p)$ curve, and the two curves do not intersect. This implies a case where the relative density of consumers and shops is so low that the incentive to use electronic money does not work. Specifically, it represents a situation where there

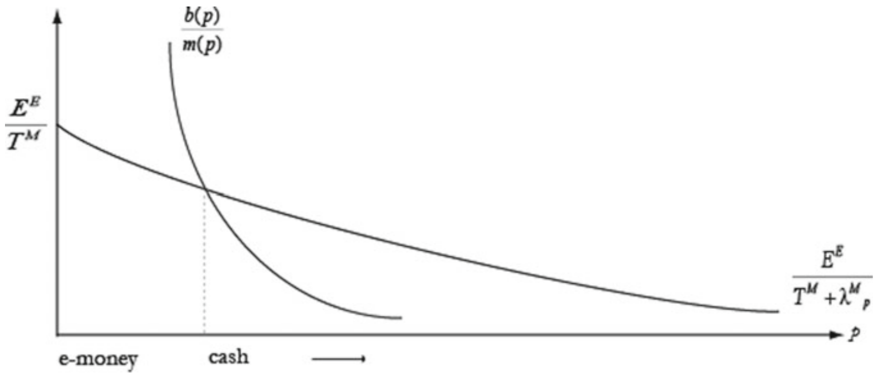

Fig. 4.4 A simple division between e-money and cash. *Source* Shy and Tarkka (1998), Fig. 3

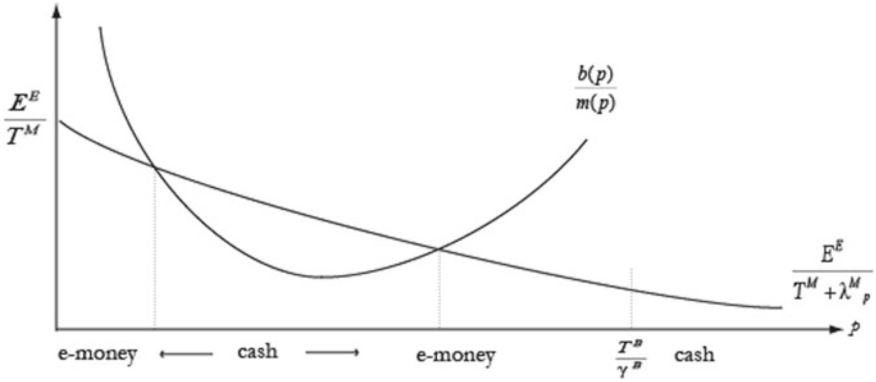

Fig. 4.5 A complex division between e-money and cash. *Source* Shy and Tarkka (1998), Fig. 4

is no need to use e-money, such as a souvenir shop in the countryside with a low population density, because few tourists visit the shop and the investment cost of payment and communication equipment is much higher than the time cost.

4.5 Implications for Monetary Policy

In this section, we will consider whether the emergence of e-money will reduce the effectiveness of monetary policy of the central bank that supplies money, and what restrictions should be imposed on issuers of e-money in order to maintain the effectiveness of monetary policy.

The currency aggregate (M1) by the narrow definition consists of cash (C) and deposit (D). Let us further consider the multiplier effect when electronic money (EM)

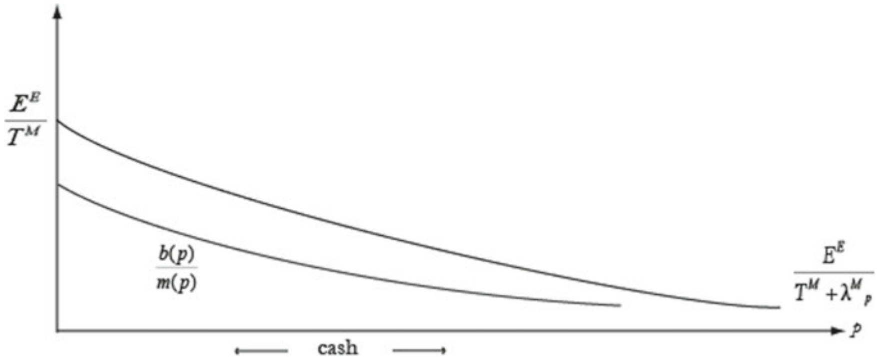

Fig. 4.6 The case of no e-money. *Source* Shy and Tarkka (1998), Fig. 5

is included in the model. As we saw in the previous section, there is substitutability between e-money and cash, and as the use of e-money expands, the use of cash will decline. If the use of cash declines, reserve deposits are also likely to decline. On the other hand, the decline in cash use could be recovered to some extent by imposing a reserve deposit requirement on e-money.

Under the current system, e-money issuers are not required to maintain accounts and reserve deposits at the central bank. However, under the Prepaid Voucher Regulation Law, an e-money issuer is obliged to (a) indicate on the prepaid voucher the amount of the voucher, the period of use, and other information, (b) deposit at least one-half of the unused balance of the advance payment accepted by the user,[9] and (c) prepare and preserve books and documents relating to the business of issuing prepaid vouchers. In addition, e-money is not included in the aggregate currency volume.[10]

Using the theory of currency multipliers, M1, the monetary base (MB), and required reserves (R) can be expressed as follows.

$$M1 = C + D \tag{4.11}$$

$$MB = R + C + E \tag{4.12}$$

$$R = r_D D + r_{EM} EM \tag{4.13}$$

where C is cash, D is deposits, EM is electronic money, E is excess reserves, r_D is the deposit reserve ratio, and r_{EM} is the reserve ratio for electronic money.

Using the currency multiplier m, the following relationship can be derived.

[9] Only when the unused balance as of the reference date (the last day of March or September of each year) exceeds the deposit standard amount (10 million yen).

[10] An argument for including e-money in *M1* is made in Berentsen (1997), but since M1 does not currently include e-money, we only consider the case where it is not included.

$$M1 = mMB \tag{4.14}$$

Find the currency multiplier from Eqs. (4.11)–(4.14).

$$\frac{M1}{MB} = \frac{C + D}{r_D D + r_{EM} EM + C + E} = m \tag{4.15}$$

Let us now see how the currency multiplier m varies with the e-money reserve ratio r_{EM} and the e-money EM.

$$\frac{\partial m}{\partial r_{EM}} = -\frac{C + D}{(r_D D + r_{EM} EM + C + E)^2} \cdot EM < 0 \tag{4.16}$$

$$\frac{\partial m}{\partial EM} = -\frac{C + D}{(r_D D + r_{EM} EM + C + E)^2} \cdot r_{EM} < 0 \tag{4.17}$$

In other words, we find that the currency multiplier decreases with the increase in the reserve ratio and e-money. However, its magnitude also depends on the deposit reserve ratio r_D, excess reserve E, cash C, and deposits D.

Next, the setting of the reserve ratio for electronic money becomes important, but how should the cash reserve ratio for electronic money be determined? The answer to this question can be derived from the relationship between the volume of currency issuance and the interbank interest rate used in Iwamura (1996, p. 165). Let a be the rate of return on assets of the e-money issuer and r_{EM} be the cash reserve ratio associated with the issuance of e-money. In this case, the revenue π earned on one unit of e-money can be expressed as follows

$$\pi = (1 - r_{EM})a \tag{4.18}$$

The cost of lost interest rate opportunity by keeping cash in reserve can be expressed as follows if the interbank interest rate is i

$$\mathrm{Cos}t = r_{EM} i \tag{4.19}$$

E-money issuers are expected to issue until the revenue from issuing e-money equals the cost of lost interest rate opportunities (we do not consider here the case of imperfect market competition among e-money issuers).

$$\mathrm{Cos}t = \pi \Rightarrow i = \frac{1 - r_{EM}}{r_{EM}} a \tag{4.20}$$

If we consider that the general equilibrium is working and the rate of return on assets a and the interbank interest rate i are equal, $r_{EM} = 0.5$ (50%) from (4.20).[11]

[11] As we saw earlier, the current cash reserve ratio for e-money is 50%, which means that we assume $a = i$.

Also, if $i = 0$, as in the case of the Japanese interbank interest rate after 2001, $r_{EM} = 1$ (100%) is required regardless of a.

To ensure the central bank's controllability over the currency, the following measures could be taken: (1) the central bank could issue electronic money and include it in the currency aggregate; (2) the issuer of the electronic money could enter the framework of the central bank's reserve deposit system and accumulate somewhat higher reserve deposits; and (3) the excess liquidity created by the electronic money could be recovered by selling central bank assets.

At present, in recognition of the convenience of e-money and in order to take advantage of the results of research and development conducted by the private sector, no unnecessary regulations have been imposed, and the spread of e-money is being monitored. However, if e-money were to significantly reduce the currency multiplier effect, the measures described above might actually come into effect.

In terms of the actual scale of payments, cash payments of less than 3,000 yen are said to be 60 trillion yen per year, and even if only 10% of that amount, or 6 trillion yen, is shifted to electronic money payments, the scale of the retail business will be substantial.

However, this is only 0.27% of the 2,192 trillion yen that was settled annually by the Zengin system in 2003. Small-amount settlements using electronic money are so small as to be insignificant in terms of monetary policy, and the current judgment is that they do not have a major impact on the way monetary policy is conducted.

4.6 Conclusion

In this chapter, we have attempted to see what kind of analysis can be done from the standpoint of financial economics on the actual state of e-money distribution in recent years. The main conclusion is that e-money can be divided into e-money, cash, and credit cards in the order of transaction costs in Sect. 4.1. It is found that the boundary is determined by the technical breakage cost of e-money and the investment cost of payment and communication equipment for credit cards. With respect to the boundary of use, we show that the actual boundary is under-utilized for e-money and credit cards, and over-utilized for cash, compared to the socially optimal boundary. In the future, if technological progress is made and the cost of payment and communication facilities is significantly reduced, the use range of electronic money and credit cards will expand, and the use range of cash will shrink.

Furthermore, Sect. 4.2 implies that the use of e-money depends not only on the comparison of transaction costs, but also on the number of consumers per shop. In other words, the use of e-money is not only facilitated by the physical transaction costs, but also by the number of consumers who use it. This is an important point in the e-money business, where the emphasis is often on the technical aspects.

Finally, the impact on monetary policy is currently negligible in scale, and it is unlikely that e-money will be discussed as a subject of monetary policy or financial administration in the foreseeable future. However, it should be pointed out that if the amount of e-money issued expands and the currency multiplier declines significantly, the central bank may need to issue e-money or require e-money issuers to join a reserve deposit system and impose a high deposit reserve ratio.

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Chapter 5
The Impact of Electronic Money on Demand for Cash: Time Series Analysis

5.1 Introduction

Recent years have seen the rapid spread of prepaid IC-type electronic payment methods known as electronic money, including Suica, ICOCA, PASMO, SUGOCA, Kitaca, Edy, nanaco, WAON, and others. The inclusion of the word "money" in the name has led to a perception of privately issued "money" being used as an alternative to cash, especially in small denominations. It is sometimes argued that privately-issued "money" will steal the seigniorage that the government and the Bank of Japan earn by issuing cash, or that private companies will be able to earn seigniorage. As things stand, it is clear that e-money is a type of payment method that requires a charge of cash and is not a substitute for cash itself.

It is also true, however, that in recent years there have been reports that the balance of small-denomination money in circulation has declined due to the impact of electronic money's replacing it. On the other hand, there is a view that the decline in small-denomination money has been affected by structural changes in Japan, such as the introduction of fee-based bank ATMs, in addition to electronic money.

The purpose of this chapter is to empirically examine the impact of e-money on the amount of money in circulation by type of money, taking into account as much as possible the structural changes in the financial system, including policy changes such as the increase in the consumption tax rate and the introduction of bank ATM charges.

We would also like to discuss how widespread e-money actually is, what the characteristics of e-money are nationally, and what the prospects for its future are, as well as what the policy issues surrounding e-money are.

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5.2 Overview of Electronic Money and Its Diffusion

With the launch of Edy by BitWallet in November 2001, IC-based e-money in Japan was introduced in earnest. In March 2004, JR East started e-money service for Suica, which had been used only for boarding passes. In October 2005, JR West also inaugurated an e-money service for ICOCA, which had been used only for boarding passes. In 2007, private railway and bus companies in the Tokyo metropolitan area launched PASMO in March, Seven & i Holdings unveiled nanaco in April, and Aeon brought in WAON in April. The year 2007 came to be called the first year of e-money.

As for the macro-statistics of e-money, the Payment and Settlement Organization Bureau of the Bank of Japan has published *Recent e-money trends* (FY2007 and FY2008) as part of its *Survey Report on Payment and Settlement Systems*. In the following, we will take a look at the actual situation based on the latest information from this report.

As shown in Table 5.1, e-money can be divided into two categories: (1) IC-type and (2) server-type. Of these, the current expansion of e-money is due to the increase in IC-type e-money. Table 5.1 also summarizes the characteristics of credit cards and debit cards, which are used as similar small-scale payment methods.

IC-type e-money can be roughly divided into three categories depending on the issuing entity: those specializing in issuing e-money, such as BitWallet, which issues Edy; those issued by distribution companies, such as nanaco and WAON; and those issued by transportation companies, such as Suica, PASMO, and ICOCA. Of these, IC-type e-money and distribution-type e-money, both of which specialize in e-money issuance, can be used throughout Japan in any stores that accept them. In contrast, transportation-related IC-type e-money could initially be used only in the issuing company's respective business area. However, mutual use of transportation-related IC e-money is now expanding, such as mutual use between Suica and ICOCA (mutual

Table 5.1 Types of small scale electronic payment methods in Japan

	Electronic money (including server type)			Credit cards		Debit card	
	Server type	IC type					
Media used access	ID, passwords	Card (Contactless)		Card (Contactless)		Card (Contact)	Card (Contact)
			Mobilephone	Mobilephone			
Services in Japan	Chocom WebMoney BitCash NETCASH	Edy Suica ICOCA nanaco WAON PASMO	Edy Suica nanaco WAON	QUICPay Visa touch iD	QUICPay Visa Touch Smartplus Pay Pass iD PITAPA	Various credit cards	J-Debit Visa-Debit
Settlement timing	Prepaid type			Postpaid type			Instant

Source Bank of Japan (2008)

use of e-money started in March 2008), and mutual use between Suica and PASMO (mutual use of e-money started in March 2007). In addition, new transportation-related IC e-money is being issued in each region of Japan.

Table 5.2 shows the total number of e-money cards issued, which exceeded 100 million in January 2009, and 105.03 million at the end of March, a year-on-year increase of 30.3%. The number of payment terminals installed in retail stores reached 480,000 at the end of March 2009, an increase of 34.1% year on year, higher than the growth rate of e-money. This is said to be due to the fact that distribution system e-money now allows mutual use across groups, and the installation of e-money-compatible vending machines began in October 2008.

Table 5.3 shows that the number of electronic money settlements reached 1,116 million in FY2008 (up 37.8% from the previous year), and the settlement value increased rapidly to 817.2 billion yen (up 45.0% from the previous year). The settlement amount per transaction was 732 yen in fiscal 2008. This per-transaction amount has remained relatively stable at around ¥700 for the past three years. It should be noted that the average e-money transaction is a small transaction of less than 1,000 yen, and this amount has also remained stable at around 700 yen.

Table 5.2 Number of electronic money issued

		() % Change from the previous year		
Year	Month	Issued number <10,000>	Mobilephone	Payment terminal <10,000>
2007	9	6,649	767	24.7
	10	6,897	793	27.7
	11	7,120	815	28.1
	12	7,326	847	28.7
2008	1	7,548	883	29.1
	2	7,800	903	29.5
	3	8,061	942	35.8
	4	8,363	969	36.4
	5	8,574	990	36.7
	6	8,761	1,011	37.1
	7	8,952	1,030	37.4
	8	9,143	1,059	38.7
	9	9,308	1,078	39.3
	10	9,497	1,095	41.2
	11	9,703	1,116	43.7
	12	9,885	1,137	44.8
2009	1	10,064	1,157	45.5
	2	10,257	1,179	47.2
	3	10,503 (+30.3%)	1,205 (+27.9%)	48.0 (+34.1%)

Source Bank of Japan (2009)

Table 5.3 Number and amount of payment by electronic money

			(%) Annual change
Year/Month	Number of payment <Million>	Amount of payment <100 million Yen>	Amount per payment <Yen>
2007	810 (n.a.)	5,636 (n.a.)	696 (n.a.)
2008	1,116 (+37.8%)	8,172 (+45.0%)	732
2007/4/6	140	931	666
7–9	218	1,484	680
10–12	225	1,612	716
2008/1-3	226	1,609	710
4–6	256 (+83%)	1,897 (+200%)	741 (+11.2%)
7–9	284 (+30%)	1,964 (+32%)	691 (+1.6%)
10–12	286 (+27%)	2,111 (+31%)	737 (+2.9%)
2009/1–3	289 (+28%)	2,200 (+37%)	761 (+7.0%)
2007/4	31	193	621
5	42	291	692
6	67	447	671
7	72	506	699
8	74	495	670
9	72	483	671
10	76	502	657
11	73	511	698
12	75	599	794
2008/1	72	511	711
2	74	516	700
3	81	582	720
4	83 (+270%)	597 (+310%)	716 (+15.4%)
5	86 (+200%)	643 (+220%)	752 (+8.7%)
6	87 (+31%)	657 (+47%)	753 (+12.1%)
7	97 (+34%)	666 (+32%)	688 (−1.6%)
8	93 (+26%)	663 (+34%)	709 (+5.8%)
9	94 (+31%)	635 (+32%)	675 (+0.7%)
10	98 (+28%)	659 (+31%)	674 (+2.6%)
11	92 (+26%)	675 (+32%)	734 (+5.2%)
12	97 (+28%)	777 (+30%)	804 (+1.2%)
2009/1	94 (+31%)	727 (+42%)	774 (+8.9%)
2	92 (+26%)	702 (+36%)	759 (+8.5%)

(continued)

Table 5.3 (continued)

			(%) Annual change
Year/Month	Number of payment <Million>	Amount of payment <100 million Yen>	Amount per payment <Yen>
3	103 (+27%)	771 (+32%)	750 (+4.1%)

Note The period total may not be exactly equal because of approximation
Source Bank of Japan (2009)

The balance of e-money issued (unused balance) was 91.2 billion yen in March 2009 (+18.0% YoY), increasing in line with the increase in the number of cards issued. It should be noted, however, that not all e-money cards issued are being actively used, and the number of dormant cards is also increasing.[1]

In addition, when the balance of e-money issued is compared with the amount of cash in circulation, it is clear that it is still very small. As of the end of March 2009, the outstanding balance of e-money was only 2.02% of the outstanding coins in circulation, 0.12% of the outstanding banknotes, and 0.11% of the total cash in circulation (the sum of the outstanding coins in circulation and the outstanding banknotes). It is clear that electronic money is not in a position to influence payment systems or monetary policy.

Electronic money and alternative small payment instruments include credit and debit cards. Table 5.4 shows a comparison of the use of small-payment methods. According to this table, the annual number of payments is by credit card, e-money, and debit card in that order. The amount of payment is also higher for e-money than for debit cards, but the amount per transaction is much smaller for e-money.

5.3 E-money Usage Based on Micro-data

So far, an overview of macro-aggregated data has shown that the use of e-money is growing rapidly. However, the empirical feeling is that the use of e-money is dependent on the availability of e-money in areas where it has been actively introduced, the use of transportation, and the availability of e-money at convenience stores and supermarkets. In addition, it can be assumed that it is the younger generation that actively uses these new types of payment methods, and moreover, it is by those who use transportation to commute to work or school. It is important to confirm how these differences in personal attributes affect the ownership and use of e-money through micro-data surveys of individuals and households.

[1] In fact, the average balance per card was 868 yen at the end of March 2009, down 9.2% on the previous year.

Table 5.4 Comparisons of small-scale payments

				(%) Annual change
	Electronic money (2008)	Debit card (J-Debit) (2008)	Credit card (2006)	(c.f.) Cashing from ATM[*1] (2007)
Card issued total <Million>	105 (+30.3)	410[*2] (n.a.)	293 (+1.0)	456[*3] (n.a.)
Total number of payments <Million>	1,116 (+37.8)	12.6 (+7.7)	4,547 (n.a.)	420 (−2.3)
Total amount of payments <10 Billion Yen>	81.7 (+45.0)	76.9 (+0.8)	3,477 (+8.1)	2,127 (−11.1)
Average amount per payments <Yen>	732 (+5.2)	61,000 (−7.6)	7600 (n.a.)	51,000 (−8.9)
Number of payment terminal <10,000>	48 (+34.1)	33 (+10.0)	155 (+12.7)	14 (+0.0)

(*1) Only withdawals from other Bank ATMs
(*2) As of the end of December 2008
(*3) As of the end of March 2007
Sources Bank of Japan (2009), Japan Debit Card Promotion Councile, and BIS “Statistics on Payment and Settlement Systems in Selected Countries”

5.3.1 Electronic Money Ownership

The Survey of Household Economy has been conducted by the Statistics Bureau of the Ministry of Internal Affairs and Communications (MIC) every month since October 2001, with the aim of capturing the actual state of personal consumption trends. Included is IT-related consumption, which has been increasing markedly in recent years, and high-priced goods and services, which are purchased infrequently. The “IT-related items” section of the Survey of Household Income and Expenditure began to include a survey on the ownership of electronic money in 2007 (January 2008).

This survey is conducted on approximately 30,000 households selected by the stratified three-stage random sampling method from all households in Japan. A total of 17,843 households with two or more persons and 1,692 single-person households were covered in FY2009, for a total of 19,535 households (65.1% collection rate). The same households are asked to continue the survey for 12 months, with a rotating panel structure in which one-twelfth of the households are replaced every month.

The 2008 report, for which detailed information is available, shows that the national average percentage of households with a household member who owns e-money is 24.4%, with the Kanto region having the highest percentage at 44.3%, followed by the Kinki region at 18.8% (see Fig. 5.1). However, there is a large diffusion gap between the Kanto region and the rest of Japan.

When asked if any household member used electronic money, 18.0% of respondents nationwide replied that they used electronic money, with the Kanto region

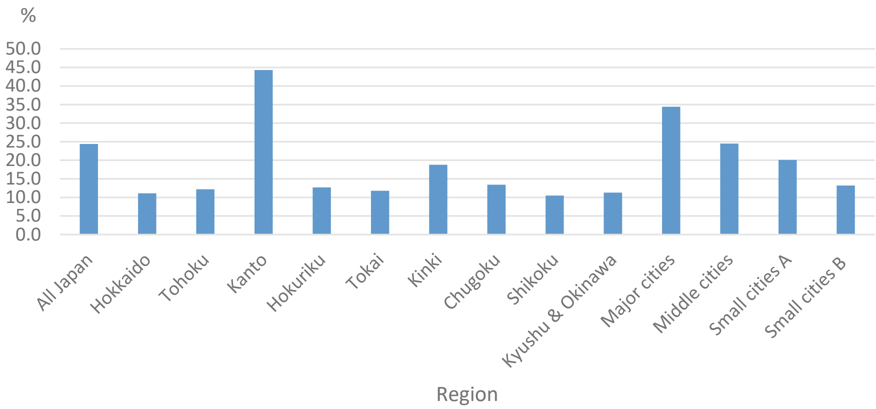

Fig. 5.1 Ownership of electronic money by region in 2008. *Source* Survey of Household Economy 2008, Statistics Bureau of the Ministry of Internal Affairs and Communications

having the highest rate at 36.9%. The most common uses were transportation (12.5%) and at convenience stores (3.2%) (see Fig. 5.2). In the Kanto region, a similar trend was observed (30.5% and 3.7%, respectively), but in other regions, with the exception of Kinki and Chugoku, convenience store use was higher than transportation use. This is probably because many stations in these regions have not yet shifted to a system of using e-money in public transportation, and because compatibility of e-money among public transportation systems has not been promoted.

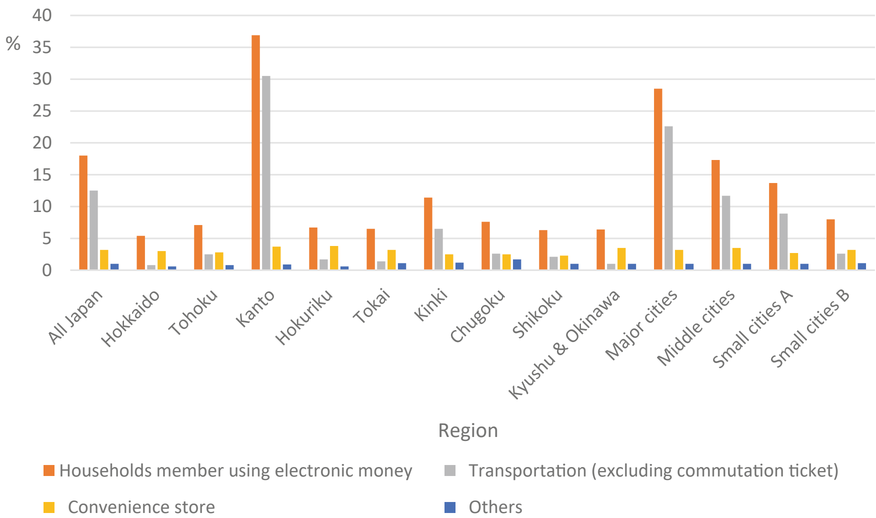

Fig. 5.2 Places and occasions electronic money were most frequently used in 2008. *Source* Survey of Household Economy 2008, Statistics Bureau of the Ministry of Internal Affairs and Communications

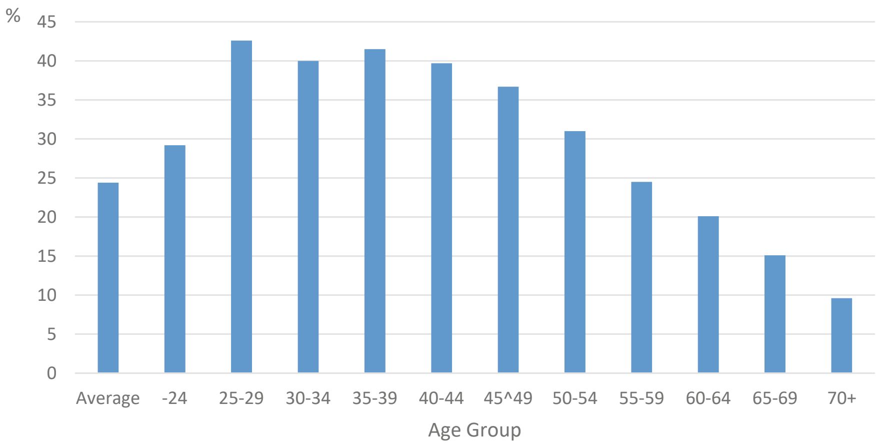

Fig. 5.3 Ownership of electronic money by age-group in 2008. *Source* Survey of Household Economy 2008, Statistics Bureau of the Ministry of Internal Affairs and Communications

Next, let us look at the status of ownership by age group (Fig. 5.3). The highest percentage of 25–29-year-olds (42.6%), 30–34-year-olds (40.0%), and 35–39-year-olds (41.5%) use a mobile phone, and these age groups are also the most frequent users of electronic money. The most frequent uses are for transportation and at convenience stores. This suggests that workers are beginning to use e-money for transportation to and from work and are also using it at kiosks and local convenience stores. On the other hand, those aged 65 and over who no longer commute regularly are limited in their opportunities to use e-money.

Looking at e-money ownership by income level, it is clear that the higher the income level, the more e-money is owned (see Fig. 5.4). If the majority of people use e-money for transportation to work or school, then differences in income should not be so relevant, but here it is clear that e-money ownership and use is correlated with income level. Of course, income is also correlated with age and occupation, so this may be a spurious correlation, and further analysis is needed on this point.[2]

Incidentally, when we look at the status of e-money ownership by occupation, it is high (over 30%) among employed people and company executives, and low (under 20%) among the self-employed and unemployed.

[2] Because transportation e-money such as Suica and PASMO can be purchased at low prices and do not require credit information to be issued, it is unlikely that income disparity reflects differences in ownership status.

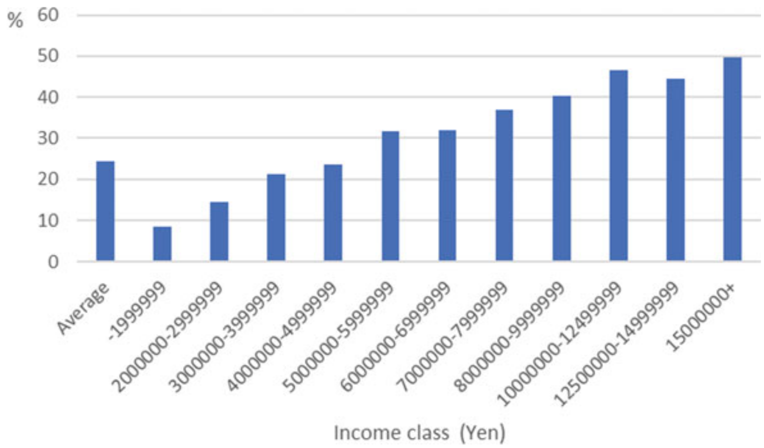

Fig. 5.4 Ownership of electronic money by level of income in 2008. *Source* Survey of Household Economy 2008, Statistics Bureau of the Ministry of Internal Affairs and Communications

5.3.2 *Choice of Small-Payment Instruments*

The choice of small-settlement instruments has been surveyed since 2007 in the Central Committee for Financial Services Public Relations' Public Opinion Poll on Household Financial Behavior.

This survey is conducted on 10,500 households selected from among all households in Japan, and as of FY2009, 4,026 households (response rate: 50.3%) were selected from 8,000 households selected by the stratified two-stage random sampling method for households with two or more persons. In addition, 2,500 single-person households were included. It is important to note that this survey was conducted by visiting and mailing only households with two or more persons, using the usual random sampling method, while single-person households were surveyed using Internet monitors who had registered in advance. As we will see later, the significant difference in e-money usage between households with two or more members and single-person households may reflect this difference in survey methodology.[3]

The 2009 survey asked, "In your household, how do you use different means of payment for daily payments (shopping, etc.) depending on the amount? Please select the payment method you use most often for each amount" [multiple answers up to two means are allowed, Q13(a)]. For households with two or more members, 3.1% choose electronic money for payments of ¥1,000 or less, and 2.2% for payments of ¥5,000 or less, which is not so high, but for single-person households, 25.2% use it for payments of ¥1,000 or less and 14.3% for payments of ¥5,000 or less, which is extremely high.

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3 The extent to which differences in survey methodology in this study make a difference in responses is a question worth examining.

As we saw earlier in the *Survey of Household Economy* by the Statistics Bureau of the Ministry of Internal Affairs and Communications, there seemed to be significant differences in ownership by region and age group, so we again tabulated the responses to Q13(a) by region and age group.[4] The results are summarized in Table 5.5 (by age group) and Table 5.6 (by region) for the 2007 and 2008 surveys.

The points observed here are as follows. (1) Electronic money is chosen as a means of payment for payments of ¥5,000 or less, especially for payments of ¥1,000 or less. (2) In terms of age, working people between the ages of 25 and 49 are the main users. (3) In terms of region, the majority of users are in the Kanto region, but there are also a relatively large number of users in Hokkaido.

As seen earlier, the high use of e-money by single-person households is clearly due to differences in survey methods, so the results here cannot be simply compared, but it can be said that the use of e-money by single-person households is relatively high.[5]

The results of this survey are consistent with the fact that the average settlement amount per transaction is 732 yen, as already seen in Sect. 5.2 of this chapter, and that the majority of e-money use is for payments of 1,000 yen or less.

Incidentally, according to Kitamura (2005), the distinction of settlement methods can be expressed as shown previously in Fig. 4.1. For settlements of tens of thousands of yen or more, credit cards and electronic payments are already being used to make settlements by transferring information using electronic media rather than cash. The introduction of electronic payment methods, such as electronic money, to very small settlements, which used to be limited to cash, suggests that the use of cash may finally be limited.

However, more strictly speaking, the total amount of a small payment does not necessarily determine the means of payment between cash, electronic money, credit cards, and other means. Electronic money may be selected when payment in units of 1 yen or 5 yen is easier than cash transfer. For example, for a payment of 300 yen, it is not so complicated to use cash, but for a payment of 1,376 yen, the payment amount is larger than 300 yen but the amount of change used for exchange is larger and more complicated, so it is quite possible to settle with electronic money. In other words, the choice between electronic money and cash is not simply determined by the total amount of money, but also by the amount of small change that needs to be exchanged. Recall my discussion in Chap. 3 on small change. If this is the case, then it is likely that electronic money will be used primarily for payments at convenience stores and supermarkets where prices are set in units of 1 yen or 5 yen, while cash or credit cards will be used rather than electronic money at department stores and high-end retailers where prices are set in units of 100 yen or 1,000 yen.

[4] The author has been permitted to use individual data from the Central Committee for Financial Services Information's *Public Opinion Survey on Household Financial Behavior* since July 2009. I would like to express my gratitude to the Committee.

[5] At the very least, it can be interpreted as revealing that, for a particular group of single-person households, nearly 20% use e-money for payments of ¥1,000 or less.

Table 5.5 Share of payment methods within the range of payment amounts by age group

(Multiple member household)

	Age group	20–24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70+	All
2007	Below 1000 (1) Cash	70.0	89.7	83.8	84.5	86.9	85.5	88.1	86.3	81.4	77.4	77.5	83.2
	Below 1000 (2) Credit Card	0.0	1.1	3.5	4.5	3.5	4.6	2.2	2.1	1.5	3.3	1.4	2.7
	Below 1000 (3) Electronic Money	0.0	5.7	4.5	4.2	4.5	4.1	2.2	1.1	2.0	0.8	0.4	2.3
	Below 1000 (4) Others	0.0	0.0	0.5	0.0	0.3	0.6	0.5	0.4	0.7	0.3	0.9	0.5
	Below 1000 (5) No Reply	30.0	3.4	7.6	6.8	4.8	5.2	7.0	10.1	14.5	18.2	19.9	11.3
	Below 5000 (1) Cash	63.6	83.3	76.4	73.4	77.7	76.2	79.8	79.2	76.2	75.7	76.5	77.1
	Below 5000 (2) Credit Card	9.1	11.1	17.2	19.0	15.1	15.2	11.9	10.3	8.0	6.9	5.4	11.1
	Below 5000 (3) Electronic Money	0.0	3.3	1.0	1.4	2.4	2.2	0.8	1.2	1.4	0.5	0.0	1.2
	Below 5000 (4) Others	9.1	0.0	0.0	0.0	0.0	0.8	0.8	0.6	0.7	0.3	1.0	0.6
	Below 5000 (5) No Reply	18.2	2.2	5.4	6.2	4.7	5.5	6.8	8.7	13.6	16.7	17.1	10.1
2008	Below 1000 (1) Cash	81.3	89.1	82.7	83.5	85.8	89.8	86.3	87.8	84.9	88.0	85.7	86.3
	Below 1000 (2) Credit Card	0.0	0.0	6.8	2.5	3.6	2.1	2.8	3.7	2.7	2.3	1.1	2.7
	Below 1000 (3) Electronic Money	12.5	1.6	5.0	6.5	5.8	3.1	2.8	1.6	1.0	0.0	0.5	2.5
	Below 1000 (4) Others	0.0	1.6	0.5	0.6	0.5	0.0	0.4	0.0	0.2	0.2	0.5	0.3
	Below 1000 (5) No Reply	6.3	7.8	5.0	6.8	4.4	5.0	7.7	6.9	11.2	9.5	12.1	8.3
	Below 5000 (1) Cash	87.5	85.1	72.9	76.3	78.2	79.8	78.3	79.4	80.6	83.3	83.8	80.1
	Below 5000 (2) Credit Card	0.0	7.5	18.3	16.3	14.2	14.0	13.3	12.2	8.5	7.7	3.9	10.8
	Below 5000 (3) Electronic Money	6.3	1.5	3.9	1.8	3.1	1.8	2.2	1.4	0.6	0.5	0.1	1.5
	Below 5000 (4) Others	0.0	0.0	0.4	0.0	0.3	0.0	0.4	0.2	0.0	0.2	0.5	0.2
	Below 5000 (5) No Reply	6.3	6.0	4.4	5.6	4.2	4.5	5.7	6.8	10.3	8.3	11.6	7.4

(continued)

Table 5.5 (continued)

(Single Household)

	Age group	20–24	25–29	30–34	35–39	40–44	45–49	50–54	55–59	60–64	65–69	70+	All
2007	Below 1000 (1) Cash	74.8	68.1	66.1	66.2	70.0	70.1	78.4	76.3	84.1	88.1	0	72.7
	Below 1000 (2) Credit Card	8.3	10.0	11.1	9.7	10.0	13.4	8.6	12.6	7.2	5.6	0	9.6
	Below 1000 (3) Electronic Money	16.5	20.4	21.7	22.7	19.2	15.7	11.5	10.5	8.4	2.8	0	16.6
	Below 1000 (4) Others	0.4	1.5	1.2	1.3	0.8	0.8	1.4	0.5	0.3	3.5	0	1.1
	Below 5000 (1) Cash	70.7	60.8	56.5	56.2	58.5	59.5	63.5	60.2	68.8	69.2	0	62.4
	Below 5000 (2) Credit Card	21.4	28.0	30.7	30.0	28.9	33.3	28.1	31.6	26.0	25.6	0	27.8
	Below 5000 (3) Electronic Money	7.0	10.1	12.1	12.0	11.9	6.3	6.3	6.6	4.6	3.2	0	8.7
	Below 5000 (4) Others	0.9	1.1	0.7	1.9	0.8	0.8	2.1	1.5	0.6	1.9	0	1.2
2008	Below 1000 (1) Cash	71.1	69.4	64.0	70.6	66.7	70.2	75.5	77.2	81.0	84.9	0	71.8
	Below 1000 (2) Credit Card	8.4	10.2	11.4	9.1	7.1	13.0	8.7	9.6	8.3	8.2	0	9.4
	Below 1000 (3) Electronic Money	17.7	19.6	22.9	19.1	25.4	16.0	14.2	10.2	8.9	6.2	0	17.3
	Below 1000 (4) Others	2.8	0.9	1.7	1.2	0.8	0.8	1.6	3.0	1.8	0.7	0	1.5
	Below 5000 (1) Cash	66.7	59.3	53.5	57.5	57.0	60.9	61.9	62.3	64.3	69.2	0	60.7
	Below 5000 (2) Credit Card	21.5	28.9	30.6	29.5	29.4	27.8	30.9	32.6	28.2	27.6	0	28.4
	Below 5000 (3) Electronic Money	9.7	11.2	14.6	12.4	13.2	10.5	6.3	4.6	5.5	3.2	0	9.9
	Below 5000 (4) Others	2.1	0.6	1.4	0.6	0.4	0.8	0.9	0.6	2.0	0.0	0	1.0

Note Single Household data are collected by the Internet Monitor Survey. By construction of questionnaires, No reply is not allowed.
Source The Central Committee for Financial Services Information, "Public Opinion Survey on Household Financial Behavior" (2007, 2008)

Table 5.6 Share of payment methods within the renge of payment amounts by region

(Multiple Member Household)

	Region	Hokkaido	Tohoku	Kanto	Hokuriku	Chubu	Kinki	Chugoku	Shikoku	Kyushu	All
2007	Below 1000 (1) Cash	82.5	80.8	78.4	83.0	84.2	85.0	88.5	79.8	89.5	83.2
	Below 1000 (2) Credit Card	0.6	1.5	3.5	1.0	4.6	3.1	0.9	2.1	1.5	2.7
	Below 1000 (3) Electronic Money	2.4	0.4	4.7	0.5	1.6	1.7	2.2	0.0	1.5	2.3
	Below 1000 (4) Others	0.6	0.0	0.6	1.0	0.4	0.6	0.0	1.1	0.4	0.5
	Below 1000 (5) No Reply	13.9	17.3	12.8	14.4	9.2	9.6	8.4	17.0	7.2	11.3
	Below 5000 (1) Cash	76.2	73.7	70.5	80.3	77.1	77.7	88.7	75.5	85.5	77.1
	Below 5000 (2)Credit Card	8.7	6.7	15.1	5.4	14.1	13.0	6.1	9.2	5.9	11.1
	Below 5000 (3)Electronic Money	1.2	0.7	2.1	0.5	0.8	0.4	1.3	1.0	1.2	1.2
	Below 5000 (4)Others	0.6	0.4	0.6	1.5	0.4	0.7	0.0	1.0	0.4	0.6
	Below 5000 (5)No Reply	13.4	18.5	11.7	12.3	7.7	8.2	3.9	13.3	7.0	10.1
2008	Below 1000 (1)Cash	89.8	84.2	82.8	83.5	88.4	87.1	89.6	89.1	89.4	86.3
	Below 1000 (2)Credit Card	3.0	2.6	3.3	1.9	3.2	2.5	1.5	1.5	2.0	2.7
	Below 1000 (3)Electronic Money	2.5	1.3	4.0	2.4	1.9	1.6	1.9	0.7	2.0	2.5
	Below 1000 (4) Others	0.0	0.3	0.3	0.5	0.5	0.2	1.2	0.0	0.2	0.3
	Below 1000 (5) No Reply	4.6	11.6	9.7	11.7	6.0	8.7	5.8	8.8	6.3	8.3
	Below 5000 (1) Cash	83.6	81.3	74.1	80.2	81.0	79.5	85.6	88.5	86.3	80.1
	Below 5000 (2) Credit Card	11.6	7.5	15.2	6.1	11.7	11.1	6.1	4.3	7.0	10.8
	Below 5000 (3) Electronic Money	1.4	0.9	1.9	0.9	1.3	1.1	1.9	1.4	1.4	1.5
	Below 5000 (4) Others	0.0	0.6	0.2	0.9	0.3	0.2	0.4	0.0	0.0	0.2
	Below 5000 (5) No Reply	3.4	9.7	8.7	11.8	5.6	8.2	6.1	5.8	5.2	7.4

(continued)

Table 5.6 (continued)

(Single Household)

	Region	Hokkaido	Tohoku	Kanto	Hokuriku	Chubu	Kinki	Chugoku	Shikoku	Kyushu	All
2007	Below 1000 (1) Cash	76.3	77.8	67.1	76.4	77.5	76.5	80.7	78.8	74.9	72.7
	Below 1000 (2) Credit Card	8.8	9.4	9.4	11.2	9.3	11.1	8.3	8.8	9.0	9.6
	Below 1000 (3) Electronic Money	12.5	11.1	22.6	12.4	12.1	10.7	10.3	12.5	15.1	16.6
	Below 1000 (4) Others	2.5	1.8	0.9	0.0	1.1	1.6	0.7	0.0	1.0	1.1
	Below 5000 (1) Cash	59.2	65.4	58.4	63.9	66.8	64.2	72.4	69.5	64.3	62.4
	Below 5000 (2) Credit Card	30.2	25.4	29.9	27.8	26.5	27.4	21.7	20.7	25.8	27.8
	Below 5000 (3) Electronic Money	8.3	8.1	11.0	7.2	5.6	6.2	5.3	8.5	9.0	8.7
	Below 5000 (4) Others	2.4	1.1	0.8	1.0	1.1	2.1	0.7	1.2	0.9	1.2
2008	Below 1000 (1) Cash	73.7	74.9	67.6	78.2	71.9	74.9	78.9	76.5	75.4	71.8
	Below 1000 (2) Credit Card	8.8	8.9	9.7	12.6	11.7	9.2	6.6	6.2	7.3	9.4
	Below 1000 (3) Electronic Money	17.0	15.6	21.3	8.0	14.3	14.2	13.2	14.8	14.9	17.3
	Below 1000 (4) Others	0.6	0.6	1.4	1.1	2.1	1.6	1.3	2.5	2.4	1.5
	Below 5000 (1) Cash	62.2	67.4	56.0	64.9	62.8	60.6	68.8	65.1	67.0	60.7
	Below 5000 (2) Credit Card	26.7	24.6	30.5	27.7	28.5	31.3	24.2	20.5	22.1	28.4
	Below 5000 (3) Electronic Money	11.1	7.5	12.2	7.4	7.9	7.3	7.0	12.0	8.8	9.9
	Below 5000 (4) Others	0.0	0.5	1.3	0.0	0.8	0.8	0.0	2.4	2.1	1.0

Note Single Household data are collected by the Internet Monitor Survey. By construction of questionnaires, No reply is not allowed.
Source The Central Committee for Financial Services Information, "Public Opinion Survey on Household Financial Behaviour" (2007, 2008)

5.4 Research on Money Demand

5.4.1 Previous Research

Discussions to date have revealed that e-money payments have expanded fairly rapidly and that the average amount per transaction is small, less than 1,000 yen. It also became clear that the number of users is unevenly distributed by region, age, occupation, and other factors, and that not all consumers in Japan possess or have access to the new means of electronic money. If we assume that the number of e-money cards issued exceeds 100 million and that 24.4% of households own e-money cards, the total number of households in Japan was approximately 50 million in 2009, which means that approximately 12.2 million households own multiple e-money cards (an average of 8 cards per household), and the remaining 37.8 million households have no relationship with e-money.

In econometrics, we should examine whether there is a difference in the demand for money between households that have e-money and households that do not have e-money. In addition, if we can obtain panel data on households that currently hold e-money, it will be possible to see whether there is a difference in money demand between households before and after holding e-money. In general, if micro-data are available, behavioral parameters can be estimated more precisely by modeling and demonstrating the behavior of individuals choosing payment methods.

In fact, empirical studies using micro-data have been actively conducted in other countries. For example, Attanasio et al. (2002) take up the diffusion of ATM cards as a new technology and estimate a Baumol–Tobin type money demand function taking into account the impact of ATM cards using the 1989–1995 Survey of Household Income and Wealth by the Bank of Italy. They find that the interest elasticity of money demand is higher for ATM card holders than for non-card holders. Lippi and Secchi (2007) use the same data as in Attanasio et al. (2002) but extend it to 2004 and consider the interest elasticity of demand for money, taking into account the conditions of ATM card use and the presence of ATM machines within a short distance. They find that the interest elasticity drops as the ATM distance becomes shorter and the elasticity approaches zero in the end. Alvarez and Lippi (2009) also use the Italian Household Income and Assets Survey (1993–2004) to extend the Baumol–Tobin model of cash demand to a dynamic framework and examine how technological progress, such as the proliferation of ATM cards, changes the preliminary demand for cash.

Stix (2004) empirically examines the impact of the widespread use of electronic payment systems (Electronic-Fund-Transfer-at-the-Point-Of-Sale, EFT-POS) and ATM cards on money demand in Austria, based on two surveys conducted by the Austrian National Bank in 2003 with 4,000 people (the actual sample was 2,800). Both EFT-POS and ATM cards have been shown to reduce the demand for money.

Duca and Whitesell (1995) use cross-sectional data from the 1983 Survey of Consumer Finances (SCF) by the Federal Reserve Board (USA) to examine the effect of credit card ownership on money and asset choice using probit estimation. Mulligan and Sala-i-Martin (2000) also use the 1989 SCF to obtain the interest elasticity of household demand for money from cross-sectional differences in asset holdings. They find that the interest elasticity is lower when the interest rate is lower, the holding of interest-bearing financial assets is proportional to the total financial assets, and the participation cost of holding interest-bearing financial assets is lower for those who participate in pension programs.

As we saw in Sect. 5.3, micro-data on e-money in Japan is finally accumulating, but it is still only available for a couple of years and does not contain enough survey items to enable a comprehensive analysis of money demand and asset choice as in the empirical studies in Europe and the United States mentioned above. So far, empirical studies on e-money in Japan have mainly taken the approach of examining the impact of adding a variable indicating the degree of e-money diffusion to the money demand function by money type using the balance of money issued at the national level.[6]

The exception is Fujiki and Tanaka (2009). This chapter examines the impact of e-money on cash holdings using cross-sectional data from the Central Committee for Financial Services Information's Public Opinion Survey on Household Financial Behavior in 2007, which we saw earlier. They report that the introduction of e-money has not had the substitution effect of reducing cash holdings, but rather has increased them in some cases. Nakata (2009) conducted a questionnaire survey on the actual status of e-money diffusion among consumers living in Fukuoka Prefecture and summarized the results. The survey revealed that consumers who use e-money frequently reduce the number of times they make cash payments, and some of them also reduce the amount of cash they hold.

One study of e-money in Japan is *The Development of Electronic Money and Financial and Economic Systems* by the Financial Research Institute. In it, Saito (2005) estimates the demand for e-money based on the estimation of the real money demand function and describes the impact of e-money through Marshall's k. Specifically, he argues that if e-money is issued that is highly substitutable for small-value payment media and saves the use of coins, which are cumbersome to use, its issuer can establish an issuance base in a zero-interest-rate environment, thereby securing a solid profit opportunity through future rises in nominal interest rates.

Prior studies on the relationship between e-money and money demand include Nakata (2007, 2009). Nakata estimates the money demand function for each money type as in this chapter. Although the functional form differs somewhat from the model in this chapter, it is confirmed that the diffusion of e-money has a significant negative correlation with the growth rate of money circulation. In addition, Nakata estimates two VAR (Vector Auto Regressive) equations, one for the money demand function by money type and the other for the e-money penetration index, and looks

[6] If we can obtain the Bank of Japan's money circulation balance by type of money by branch, we should be able to estimate the impact of e-money on money demand by region or as panel data by matching the level of e-money penetration by region using the Central Committee for Financial Information's *Public Opinion Survey on Household Financial Behavior* and the Statistics Bureau of the Ministry of Internal Affairs and Communications' *Survey of Household Economy*. It should be possible to estimate the impact of e-money on money demand by region or as panel data. If this were to be done, it would be possible to estimate money demand even more rigorously than if it were measured at the national macro level, but this is not currently possible due to data limitations.

at the impulse response function to see the impact of e-money on the money demand by money type. Table 5.7 summarizes the methodology of empirical studies based on money demand functions for e-money in Japan.

As already discussed, at present there is no detailed e-money and currency statistical information on individual settlement amounts at the micro level, so we will examine the impact of the increase in e-money payments on the demand for small change by estimating the demand function for each type of money in the aggregate. Our interest here is not in the use of e-money as a means of making small payments, but in examining how it reduces the demand for small coins such as 1 yen, 5 yen and 10 yen coins.

5.4.2 Specification of the Money Demand Function

The demand for money is one of the most extensively studied empirical areas. Historically, there are several models based on the quantity theory of money formulated by Friedman (1956, 1969), the liquidity preference model based on Keynes (1936), and the inventory model based on Baumol (1952) and Tobin (1956) Inventory Model considering transaction costs.[7] Various theoretical models have been proposed and demonstrated, including Sidrauski's (1967) Shopping Time Model, Clower's (1967) Cash-in-Advance Model, and Tobin's (1958) Portfolio Model, have been proposed and demonstrated.[8]

In this chapter, instead of comparing these models, we consider a general money demand function and add the effects of demographic change and the increase of new payment methods such as electronic money to it.[9]

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[7] Much of the recent empirical work on the demand for money that takes into account the introduction of new financial technology is based on this Baumol–Tobin type model. The Baumol–Tobin model optimizes the portfolio choice between interest-bearing financial assets and money under the trade-off relationship between fees on the sale of financial assets and lost interest income, and the income elasticity and interest elasticity of money demand are derived theoretically. It should be noted that the empirical demonstration of this model shows that the pattern of money stock adjustment differs depending on the period taken for the demand for money. If income is paid on a monthly basis and data on money demand and the interest rate are monthly, the intra-month adjustment of the money stock cannot be seen in the data. In this case, we should think that we are looking at how annual income and annual financial asset holdings are adjusted on a monthly basis. Similarly, the annual data do not allow us to check intra-year adjustments. Caution should be exercised in setting and interpreting time periods in empirical studies.

[8] For theoretical expositions of these models, see Serletis (2007), McCallum (1989), Tobin and Golub (1998), and Walsh (2003). A recent survey of empirical studies is Sriram (2001).

[9] In this chapter, we use the usual money demand function, but it should be noted that the demand for money in the period of e-money diffusion should take into account the two-sided markets discussed by Rochet and Tirole (2011) and Rysman (2009). In other words, at a time when retailers that accept electronic money as a means of payment and those that do not will coexist, it will be necessary to hold both electronic money and cash in order to be able to make payments in both. In this case, there is a problem of choice of payment method for the retailer and a problem of choice of payment method for the consumer, meaning that payment can be made only when both payment methods

Table 5.7 Empirical researches on money demand function taking into account of electronic money in Japan

Authors	Period	Estimation methods	Money type	Explanatory variables				Unit root test	Co-integration test	Structural change test	Error correction term
				Scale variables (Economic activities, population)	Interest rate	Price index	Other variables				
Saito (2005)	April 1983–March 2001 monthly	Dynamic OLS	Coins including 500 Yen	Industrial production	Over night Call rate	Consumer price index		Yes	Gregory and Hansen (1996)	Hansen (1992) Kuo (1998)	No
			1000 Note								
			5000 Note								
			10,000 Note								
Nakata (2007) ①	June 2002–June 2007 monthly	OLS	1 Yen Coin	Commercial sales	Real deposit interest rate	Use as a deflator	Electronic money daily transaction cases of suica	Augmented Dickey Fuller Test, Phillips-Perron Test	–	–	No
			5 Yen Coin								
			10 Yen Coin								
			50 Yen Coin								
			100 Yen Coin								
			500 Yen Coin								

(continued)

Table 5.7 (continued)

Authors	Period	Estimation methods	Money type	Explanatory variables				Unit root test	Co-integration test	Structural change test	Error correction term
				Scale variables (Economic activities, population)	Interest rate	Price index	Other variables				
			1000 Yen Note								
			5000 Yen Note								
			10000 Yen Note								
Nakata (2007) ②	June 2004–June 2007 monthly	OLS VAR (Impulse Responce)	1 Yen Coin	Commercial sales	Real deposit interest rate	Use as a deflator	Electronic money daily transaction cases of Suica	Augmented Dickey Fuller Test, Phillips-Perron Test	–	–	No
			5 Yen Coin								
			10 Yen Coin								
			50 Yen Coin								
			100 Yen Coin								
			500 Yen Coin								
			1000 Yen Note								
			5000 Yen Note								

(continued)

Table 5.7 (continued)

Authors	Period	Estimation methods	Money type	Explanatory variables				Unit root test	Co-integration test	Structural change test	Error correction term
				Scale variables (Economic activities, population)	Interest rate	Price index	Other variables				
			10000 Yen Note								
This study	November 1994–December 2008 monthly	OLS	1 Yen Coin	Industrial production/Commercial sales	Unsecured call rate Postal saving rate 1 Year Deposit Rate Less than 1 year Deposit rate Ordinary Deposit Rate	Use as a deflator	Electronic money Daily transaction cases of Suica	Augmented Dickey Fuller Test, Phillips-Perron Test	–	–	Yes
			5 Yen Coin								
			10 Yen Coin								
			50 Yen Coin								
			100 Yen Coin								
			500 Yen Coin								
			1000 Yen Note								
			5000 Yen Note								
			10000 Yen Note								

It is easy to imagine that population increases aggregate money demand: even if per capita money holdings remain constant, an increase in population increases the demand for goods transactions, and the demand for money increases correspondingly. Electronic money, on the contrary, enables small payments of any amount, and the incentive to hold small change decreases. Of course, the infrastructure for e-money payments is not so well developed that all economic transactions can be settled electronically. However, in densely populated metropolitan areas where economic transactions are concentrated, electronic payments tend to increase not only because consumers have a motivation to keep less money, but also because retailers have a motivation to save money by speeding up the settlement process and avoiding errors in change calculation associated with cash payments. In addition to the consumer's motivation to own money, the retailer's motivation to save money is also increasing.

In the following, we consider the following money demand function.

$$\ln\left(\frac{M_t}{P_t}\right) = \mathrm{f}(y_t, i_t, em_t, z_t) \tag{5.1}$$

where M_t is the demand for money, P_t is the price level (or the face value of each type of money in the case of gold-type money), y_t is the real economic activity (the real consumption level c_t may be used depending on the formulation of the model), i_t is the interest rate, em_t is the electronic money factor, and z_t is the population factor.

This Eq. (5.1) is further linearly approximated for the empirical model and organized as follows.

$$lnm_{jt} = a_0 + a_1 lny_t + a_2 i_t + a_3 \ln(em_t + 1) + a_4 lnz_t + SDM_t + \varepsilon_t \tag{5.2}$$

where $m_{jt} = M_{jt}/P_{jt}$ and j means that it is money (denomination) type j. Thus, m_{jt} represents the amount of type of money or banknotes in circulation; SDM_t is a seasonal dummy.

However, Eq. (5.2) does not take into account the structural changes and cyclical factors during the estimation period. Therefore, following the standard method of time series analysis in recent years, we remove the seasonal adjustment and cyclical factors from the original data, and furthermore, we take the first-order difference to ensure stationarity.[10]

are matched. Needless to say, since monetary (cash) payments are always accepted, the incentive to hold money (cash) is not expected to decline even if e-money becomes considerably popular. The consumer's choice of payment method is not simply determined by his or her preference for the payment method, but rather by the acceptability of various payment methods at retail stores and the consumer's risk aversion to not being able to make a payment. When e-money becomes accepted by all retailers in the long run, the demand for money will be lower than in the diffusion period, but eventually e-money will become neutral in the sense that it will have no effect on the demand for money.

[10] The original data were processed as follows. (1) Various currency data since October 1985 are seasonally adjusted by the X12 method of the US Census Bureau. (2) Variables expressed in nominal

$$\Delta lnm_{jt} = a_0 + a_1 \Delta lny_t + a_2 \Delta i_t + a_3 \Delta \ln(em_t + 1) + a_4 \Delta lnz_t + \varepsilon_t \tag{5.3}$$

This model is a dynamic money demand function, and an error correction term is introduced to take into account the long-run equilibrium relationship between the volume of money in circulation and its explanatory variables.[11] This is a method of estimation in which the deviation between the equilibrium value and the realized value is regarded as the deviation from the long-run equilibrium. This is an estimation method in which the deviation between the equilibrium value and the realized value is regarded as the deviation from the long-term equilibrium and included in the estimation formula. This estimation method enables us to confirm whether the force to return to equilibrium is working when deviation from the long-term equilibrium occurs. There are two possible ways to create the error correction term. One is to use the residual of the basic estimation Eq. (5.2) as the margin of deviation, and the other is to estimate the amount of money in circulation based on the level of economic activity and the interest rate, and use the residual of that as the margin of deviation. The latter is used here.

$$\begin{aligned}\Delta lnm_{jt} = a_0 + a_1 \Delta lny_t + a_2 \Delta i_t + a_3 \Delta \ln(em_t + 1) + a_4 \Delta lnz_t \\ + a_5\big(lnm_{jt} - \widehat{a_1} lny_t - \widehat{a_2} i_t\big) + \varepsilon_t\end{aligned} \tag{5.4}$$

Here, after a_5 is the error correction term. If the sign of a_5, which is the coefficient of the error correction term, is negative, it indicates that there is a movement back to long-term equilibrium in the following period or later when deviations occur.

Equation (5.4) is the empirical model used in this chapter. The final model selection was made by fitting the actual data to this model.[12] The sample size is 170. The

money values are divided by the CPI Composite Index and realized. Interest rates are realized by subtracting the year-on-year rate of change in the CPI Composite Index from the interest rate index. (3) The Hodrick–Prescott filter is used to remove cyclical fluctuations. (4) Natural logarithm is used. For stationarity, we conducted the Augmented Dickey Fuller test and Philips and Perron test. Through these tests, it was confirmed that stationarity was ensured by taking the first-order difference.

[11] For the error correction model, see Iwata (1992, Chapter 5), Serletis (2007, Chapter 12), and others.

[12] In the process of model selection from Eqs. (5.2) to (5.4), the following various dummy variables, which are thought to have an impact on money demand, were included in the estimation. (1) A dummy for a 5% consumption tax (the consumption tax was raised from 3 to 5% on April 1, 1997). (2) Consumption tax totalization dummy (consumption tax was changed from the external tax system to the totalization system on April 1, 2004). (3) Bank ATM charge dummy (The Bank of Tokyo-Mitsubishi became the first major bank to charge a fee for exchanging 51 or more large bills at a bank ATM on February 17, 2003). (4) New 500 yen coin issue dummy (The new 500 yen coin was issued in August 2000 due to an increase in counterfeiting of the old 500 yen coin). (5) New banknotes dummy (new-style 10,000 yen, 5,000 yen, and 1,000 yen notes were issued in November 2004). (6) Zero-interest-rate dummy (The zero-interest-rate policy started in February 1999 and was lifted in August 2000, but it started again in March 2001 and was lifted in July 2006. The zero interest rate was also introduced in December 2008.) In the error-correction model in Eq. (4), the effects of these institutional changes became insignificant and were removed in the process of model transformation, and no dummy variables were included.

estimation period is from November 1994 to December 2008 (sample size: 170).[13] The final variables used are: m_{jt} is the "volume of money and Bank of Japan notes in circulation," y_t is the "industrial production index," c_t is the real "commercial sales value (billion yen)," i_t is the "over-the-counter (OTC) interest rate for less than one year (percent)," em_t is the "cumulative number of Edy + Suica cards issued (billion)" and z_t is "population (billion people)".

5.5 Interpretation of the Empirical Results

Table 5.8 summarizes the estimation results. This result shows that the sign condition required by the theory of money demand function is almost satisfied. That is, the coefficients on the level of real economic activity are mostly positive and significant, and the coefficients on the less-than-one-year term OTC interest rate are mostly negative and significant.

The coefficients of population growth rate are positive and significant for almost all the money types. This implies that population growth increases the demand for money.

As for the diffusion of electronic money, all coefficients for the 1 yen, 5 yen, 10 yen, and 50 yen coins are negative and significant except for the 1 yen coin. The coefficients for the 100 yen coin and 500 yen coin are negative but no longer significant, while those for the 1,000 yen note are positive and significant, and those for the 5,000 yen note and 10,000 yen note are no longer significant.

The error correction term is negative and significant for the 1 yen coin, 10 yen coin, 50 yen coin and 100 yen coin. The error correction term is negative and significant for the 1 yen coin, the 10 yen coin, the 50 yen coin and the 100 yen coin, while it is positive and significant for the 1,000 yen note and the 5,000 yen note. In other words, when small denomination coins deviate from the long-run equilibrium, there is a tendency to return to equilibrium in the following period.

Since Eq. (5.4) was a model that took the first-order difference of logarithms, the estimated coefficient directly represents the elasticity of demand for money of the variable. In addition to the information in Table 5.8, we also include the estimation results of commercial sales as an explanatory variable, and Table 5.9 summarizes the elasticities.[14]

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[13] The estimated period includes the period before the introduction of electronic money and the period when interest rates fluctuated to some extent.

[14] Nakata (2007, 2009) performed VAR estimation and used the parameters to obtain an impulse response function. This dynamically tracks how shocks related to e-money affect the demand for coins and banknotes, and provides a better picture of the long-term effects than a snapshot of elasticity as in this chapter. However, in our judgment, the parameters of the money demand function itself cannot be considered stable at the present time when electronic money is rapidly spreading, and we do not think it is appropriate to use an impulse response function that assumes that the parameters are stable for a certain period.

Table 5.8 Estimation results of money type demand function

Dependent variable	Money type demand								
	1 Yen Coin	5 Yen Coin	10 Yen Coin	50 Yen Coin	100 Yen Coin	500 Yen Coin	1000 Yen Note	5000 Yen Note	10000 Yen Note
Industrial production index	0.0345 (0.6379)	0.0534 (1.5211)	0.1630*** (9.7223)	0.0490 (0.9459)	0.1208*** (6.1675)	0.1503*** (2.9173)	0.1189*** (6.8639)	0.3269*** (7.4339)	−0.0687 (−1.4055)
Less than 1 year deposit rate	−0.4965*** (−3.7290)	−0.3056*** (−3.0748)	−0.2334*** (−3.7018)	−0.5025*** (−3.3949)	−0.2616*** (−4.5859)	−0.6286*** (−4.8571)	−0.0536 (−1.2549)	0.1475 (1.2707)	−0.5375*** (−4.1807)
Edy and Suica total Issued	−0.0005 (−1.6474)	−0.0007** (−2.0511)	−0.0002* (−1.8395)	−0.0005** (−2.0447)	−0.0002 (−1.0570)	−0.0002 (−0.5392)	0.0002* (1.9430)	0.0001 (0.4724)	−0.0003 (−0.5933)
Population	3.8823*** (4.0987)	7.2933*** (10.4726)	3.6648*** (10.5767)	5.3794*** (6.0040)	2.9547*** (5.6782)	12.2944*** (9.4860)	5.8417*** 19.8614	6.5867*** (7.7003)	27.8815*** (26.6513)
Error correction term	−0.0280** (−2.4911)	−0.0057 (−0.6351)	−0.0303*** (−3.6152)	−0.0329*** (−3.0618)	−0.0039** (−1.9910)	−0.0011 (−0.8642)	0.0030*** (4.4769)	0.0034*** (3.6591)	0.0005 (0.6356)
Constant	−0.0001 (−0.8019)	−0.0009*** (−12.8883)	−0.0004*** (−11.5571)	−0.0003*** (−3.2132)	0.0006**** (10.7949)	0.0018*** (12.6393)	0.0009*** (23.4018)	0.0019*** (16.8298)	0.0015*** (17.2034)
Adjusted R-squared	0.7373	0.7829	0.8161	0.7455	0.8328	0.8840	0.9030	0.7463	0.9722

(Note 1) Upper colum is coefficient, Lower colum is t-value. Coefficients indicate *** at 1%, ** at 5%, * at 10% significant levels.
(Note 2) t-value is based on the robust standard error.

Table 5.9 Various elasticities of money type demand

Authors	Economic activities	Money type	Elasticities			Opportunity costs (Semi-elasticities)
			Economic activities	Electronic money	Population	Interest rate
Saito (2005)	Industrial production	Coins including 500 Yen Coin	1.13500	–		−0.03400
		1000 Yen Note	0.70100	–		−0.01500
		5000 Yen Note	1.37300	–		−0.03100
		10000 Yen Note	1.73700	–		−0.05900
Nakata (2007) ①	Commercial sales	1 Yen Coin	0.00120***	−0.00040***		0.00003***
		5 Yen Coin	−0.00040	−0.00060***		0.00001
		10 Yen Coin	−0.00180***	−0.00030***		−0.00001
		50 Yen Coin	−0.00230***	−0.00020***		0.00001
		100 Yen Coin	−0.00100***	−0.00020***		0.00000
		500 Yen Coin	−0.00670***	−0.00100***		−0.00006
		1000 Yen Note	−0.00550***	−0.00060***		−0.00009
		5000 Yen Note	−0.00010	0.00000		−0.00002
		10000 Yen Note	0.00600***	−0.00300***		0.00015*
Nakata (2007) ②	Commercial Sales	1 Yen Coin	0.00070***	−0.00010***		0.00000
		5 Yen Coin	0.00410**	−0.00070***		−0.00003
		10 Yen Coin	0.00090	−0.00040***		−0.00001
		50 Yen Coin	0.00560***	−0.00080***		−0.00004*
		100 Yen Coin	−0.00010	−0.00020***		0.00000

(continued)

Table 5.9 (continued)

Authors	Economic activities	Money type	Elasticities			Opportunity costs (Semi-elasticities)
			Economic activities	Electronic money	Population	Interest rate
		500 Yen Coin	0.01300**	−0.00250***		−0.00011
		1000 Yen Note	0.01490***	−0.00240***		−0.00013***
		5000 Yen Note	−0.00410	−0.00240*		0.00000
		10000 Yen Note	0.00720*	−0.00170***		−0.00005
This study①	Industrial Production	1 Yen Coin	0.03445	−0.00052	3.88227***	−0.49649***
		5 Yen Coin	0.05344	−0.00074**	7.29332***	−0.30557***
		10 Yen Coin	0.16297***	−0.00022*	3.66476***	−0.23338***
		50 Yen Coin	0.04903	−0.00052**	5.37939***	−0.50251***
		100 Yen Coin	0.12079***	−0.00016	2.95466***	−0.26161***
		500 Yen Coin	0.15031***	−0.00016	12.29443***	−0.62862***
		1000 Yen Note	0.11891***	0.00015*	5.8417***	−0.05357
		5000 Yen Note	0.32693***	0.00009	6.58673***	0.14748
		10000 Yen Note	−0.06870	−0.00026	27.88154***	−0.53753***
This study②	Commercial sales	1 Yen coin	0.0569	−0.0007**	4.3873**	−0.5147***
		5 yen Coin	0.1146**	−0.0008**	10.9498***	−0.2284**
		10 Yen Coin	0.2196***	−0.0002*	6.3890***	−0.3047***
		50 Yen Coin	0.0835	−0.0007**	6.9198***	−0.4987***

(continued)

The coefficient for the elasticity of real economic activity is around 0.15. For interest rate elasticity, the coefficient is around −0.2 to −0.5. For e-money, the order of magnitude is even lower and is around −0.0002 to −0.0007 for significant money types. Comparing the orders of magnitude of these values, it is clear that the impact of e-money on money demand is insignificant compared to the impact of other variables.

Table 5.9 (continued)

Authors	Economic activities	Money type	Elasticities			Opportunity costs (Semi-elasticities)
			Economic activities	Electronic money	Population	Interest rate
		100 Yen Coin	0.1648***	−0.0003*	6.1308***	−0.2698***
		500 Yen Coin	0.2548***	−0.0003	19.8933***	−0.5341***
		1000 Yen Note	0.1525***	0.0004**	9.6999***	−0.0747
		5000 Yen Note	0.4146***	0.0007**	13.0871***	−0.0379
		10000 Yen Note	−0.1025	−0.0002	29.9680***	−0.3921**

If we consider e-money as an additional new means of payment, the current rapid spread of e-money has had a reasonably significant impact on money demand, but the impact is expected to decline further once the spread of e-money has slowed down. It should also be noted that the diffusion of e-money may affect interest elasticity, as Lippi and Secchi (2007) pointed out that interest elasticity is lower for people who have ATM machines close at hand.

In this chapter, the elasticity of the population growth rate is estimated to be 5 to 10, which is extremely elastic. The reason for the extraordinary elasticity of the population growth rate needs to be considered further, including the possibility that this variable is a proxy for some other variable.

Next, let us compare the elasticity between the different money types (denominations). The elasticity of economic activity increases from the 1 yen coin to the 1,000 yen note. In contrast, the elasticity of interest is around −0.2 to −0.5, with little difference between the different denominations. As for electronic money, the elasticity of small denominations is relatively large, and the higher the denomination, the lower the elasticity and the less significant it becomes.

5.6 Policy Implications

5.6.1 Technological Progress and Security Issues in Electronic Money

The current mainstream of electronic money in Japan is in the form of contactless IC cards, the technology for which is called FeliCa, and almost all electronic money uses this technology. The advantage of this card is that it can be used for high-speed authentication and payment processing at automatic gates of transportation systems, building entry, and cash registers of convenience stores and kiosks. Contact-type IC cards are more secure in terms of security, as they require the entry of an ID and password, but they take too much time and are not suitable for authentication and settlement at automatic transportation gates or convenience stores. At present, there is a limit to the amount of balance that can be stored in e-money, and it is unlikely that there have been any cases where someone has deciphered the encryption on a contactless IC card and stolen the balance of e-money without coming into contact with another person, but if e-money issuers raise the balance limit in the future, the incentive to decipher the encryption may increase.

Private companies are urged to make efforts to increase the security of current contactless IC cards.[15] At the same time, however, we must not become overly risk-averse and overemphasize security issues to the point of blocking private-sector initiatives for technological innovation.

If e-money is considered to be a new means of payment, it has been judged that it has had little impact on the payment and financial systems at present, when it accounts for only about 0.1% of total payments. So, will there be any government involvement in the e-money business that is being promoted on a private sector basis? If the government considers this to be a kind of technological innovation in the field of payment methods, and if it functions in a neutral manner, then it would make sense to watch the spread of e-money on a private-sector basis. As long as other payment methods such as cash, bank transfers, postal transfers, and credit cards are widely available, there is no need for the government to correct or subsidize regional differences in the spread of electronic money.

5.6.2 Resource Savings for Small Denominations of Money

It turns out that electronic money is not only used for small payments of 1,000 yen or less, but also for payments with fractions of a yen or five yen. The U.S. penny coin is made of zinc, but due to the recent sharp rise in the price of the metal, it costs about 1.4 penny to make a penny coin, and there have been repeated arguments that the penny coin should be abolished as a supplement to the basic unit of currency, the dollar. In fact, the 1 yen coin is made of aluminum, the 5 yen coin is made of an alloy of copper and zinc (brass), and the 10 yen coin is made of bronze (an alloy of copper and tin containing zinc). For small-denomination coins, at least the 1 yen coin, it is assumed that the raw material costs and production costs exceed the face value.[16]

[15] See Suzuki et al. (2008) for more information on security measures surrounding electronic money.

[16] The fact that small-denomination coins in the European Middle Ages were worth more than their face value resulted in a shortage of small coins as a result of storing them or using them for other purposes is discussed in Sargent and Velde (2002). If the metal value of small denomination coins continues to rise above their face value, something similar to the situation in the European Middle Ages may happen. However, since we now have electronic money as a means of payment, it is unlikely that we will have as much trouble making payments as people did in the Middle Ages. See

As we have already seen, the distribution of e-money users is skewed toward urban areas, and it cannot be assumed at this point that e-money will be used on a nationwide scale, and in that sense it is likely that small denomination coins will continue to circulate. If the empirical results of this chapter are correct, demand for small denominations such as the 1 yen, 5 yen, and 10 yen coins will certainly decline. We would like to point out that this will also help to conserve precious metal resources.

In addition, if the future consumption tax rate is not a rounded figure, there may be many cases where the amount paid will be a fraction of that amount even if the tax is set within. In this case, too, more and more people will choose to pay with electronic money, which could also lead to savings in the metal resources used for coins. In fact, it is recorded that the demand for 1 yen and 5 yen coins increased when the consumption tax was introduced in 1989 and when the consumption tax rate was raised in 1997. However, as e-money spreads steadily, the impact of a consumption tax rate hike on the small-denomination coins would be negligible.

In addition, settlements of one yen or less can be made on electronic money, which may allow for greater flexibility in pricing. Furthermore, e-money payments are also known to save time, and are being introduced in major stations, kiosks, convenience stores, and cafeterias of large corporations in the Tokyo metropolitan area, where payments are concentrated.

5.6.3 Legal System and Accounting Standards

Until now, the law regulating e-money has been the Prepaid Voucher Regulation Law (Prepaid Card Law), which imposes an obligation to deposit at least half of the balance if the unused balance on the base date exceeds 10 million yen. Until now, this law only applied to IC-type e-money (store value type) and not to server-type e-money. Therefore, in June 2009, the Law on Funds Settlement (Law No. 59 of 2009) was promulgated, and server-based e-money was subject to the same regulations as IC-type e-money, and the Prepaid Card Law was abolished.

Although not the subject of this chapter, points, which are equivalent to premiums or discounts given by companies for the purpose of sales promotion, can be exchanged for e-money, and it is becoming possible to purchase products with a single set of points on a point exchange site or to convert them into cash through online banking. At present, points are discussed in the framework of consumer protection and competition policy under the Act Against Unjustifiable Premiums and Misleading Representations and the Anti-monopoly Act, and the discussion has not converged to the point of inclusion in the Law Concerning Funds Settlement in relation to electronic money, which remains an issue to be considered in the future.

Chaps. 2 and 3 for a discussion of commercial transactions and the setting of monetary units when change is in short supply.

There is also a major debate regarding the accounting treatment of companies that issue points. Under International Financial Reporting Standards (IFRS), the issuance of points should be recorded as a liability and the "fair value" of the points should be excluded from sales, based on the interpretation that points are a "deferred portion of future sales. However, this method would inflate the deferred revenue (liability) and lower the company's profitability index, and there has been much opposition from the corporate side, and no agreement has been reached on the accounting treatment of the points.

Similar to points, there is a type of local currency. It is used as a means of exchanging goods and services only within a region, and is used not only for economic effects but also as a means of stimulating volunteer activities and exchanges in the region. In recent years, it has become possible to record this local currency on electronic money such as Suica and PASMO.[17] At present, this information is stored separately from electronic money, but just as airline mileage and points at mass merchandisers have somehow become exchangeable for electronic money, we should assume that local currencies may become national currencies through private-sector exchange markets.

5.7 Conclusion

In this chapter, after looking at the overview of e-money and its actual diffusion, we examined the actual usage based on more detailed micro-data. The results show that 24.4% of households in Japan have e-money, with the Kanto region having the highest percentage at 44.3%, and that the majority of users are in the 25–49 age group and use e-money for transportation. In addition, e-money is mainly chosen for payments of less than 1,000 yen, and its usage rate is likely to be high among single people.

Furthermore, as a result of estimating the money demand function, it is clear that the demand for small denominations of 50 yen coins and below has declined due to the spread of electronic money. On the other hand, the demand for 1,000 yen bills has increased due to the spread of e-money, which is used for recharging and other purposes, indicating that e-money is not a one-way substitute for money. Although not demonstrated here, the results of Fujiki and Tanaka (2009) and other studies indicate that during the diffusion period of e-money, the demand for money may temporarily increase because the need to hold both money and e-money arises due to uncertainty about the acceptability of e-money. In addition, the money demand elasticity of e-money is extremely low, and the impact of e-money on money demand

[17] In Kunitachi City, where Hitotsubashi University is located, a local currency called "Kunitachi Point" is issued by the Kunitachi City Commerce and Industry Association, and points are earned for purchases at participating stores (1 point for every 105 yen purchases). These points are recorded separately from the electronic money on Suica and PASMO. One Kunitachi point is worth 1 yen.

is found to be limited even during periods of rapidly expanding use such as the current period.

Looking at these results, it can be expected that e-money will be one of the payment methods and that it will be neutral to the real economy in the long run, and that it will have no impact on money demand in the long run. The widespread use of e-money is a kind of infrastructure development, which may provide business opportunities for companies involved in it, but it is unlikely to have an impact that will change the nature of the real economy.

However, electronic money is not limited to time-saving settlements at automatic ticket gates of transportation systems and convenience stores; it also has a high potential to become a highly convenient means of payment for the elderly who find handling small change cumbersome in an aging society. Furthermore, electronic money is also an effective means of saving resources in the form of small denominations of money and expanding the degree of freedom in setting prices. It would be desirable to make active use of these new technologies.

It is necessary to develop a legal system and set accounting standards for this purpose. It will also be important to develop and publish e-money-related statistics in order to understand the actual situation surrounding e-money.

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Chapter 6
Can We Stabilize the Price of a Cryptocurrency? Understanding the Design of Bitcoin and Its Potential to Compete with Central Bank Money

6.1 Bitcoin as a Virtual Registry System

Bitcoin (Nakamoto, 2008) is an electronic cash system designed to work without central management. Despite recent enthusiasm, Bitcoin (BTC) and other so-called cryptocurrencies are not ideal as means for payment, because of instability of their market prices against major currencies. This chapter explores the problem of such instability from the viewpoint of economics and proposes a new monetary policy for stabilizing the values of these cryptocurrencies. First, we begin by describing the institutional details of Bitcoin.

Circulation of Bitcoin[1] as a digital asset is guaranteed by an authentication process between traders. This process consists both of an asymmetric key cryptosystem and by competition between coin-releasing "miners" who validate transactions to prevent double spends by traders. It is important to recognize that it is operationally feasible for traders to authorize transactions by means of a digital signature, based on an asymmetric key cryptosystem. It is by far more difficult to validate transactions of Bitcoin, or other digital assets, whilst preventing double spending of assets. For paper money and checks, anti-counterfeit technology, such as holograms and signatures, prevents forgery. But the state of digital assets never deteriorates and it is not a simple task to identify a genuine transaction from a forged one.

Many electronic securities and electronic money systems employ either a centralized (a node with hub function) trading system or an IC card system with a secret key that prevents such doubled spending. The former system requires a centralized administration with a reasonable governance structure. The latter system requires an IC card operation. These systems may transfer incidents of regulation and other institutional risks to the owners of digital assets.

[1] In this chapter, we refer to Bitcoin as either a software package that can buy and sell Bitcoin or an operational system under which miners are voluntarily involved. It does not necessarily reflect the original idea of Nakamoto (2008).

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In Bitcoin the validation of transactions (preventing double spending) is made possible by sharing the virtual registry book that contains all information on transactions and ownership of Bitcoin. The virtual registry book is always open to every participant, so any double spend is easily identified. Bitcoin gives the impression that it is a set of independent gold-like coinage assets with its co-option of "mining" and "coin" phrases. But Bitcoin more closely resembles a real estate register or record in which the new owner of each lot of real estate is recorded whenever a new transaction takes place. This virtual real estate register record contains 21 million lots (i.e., 21 million BTCs) before sub-dividing.[2] To issue Bitcoin is to attach an ID number to each BTC lot, and a settlement of BTC is to replace the ID number by a new number.[3]

As of October 2018, a total of 17.31 million BTCs had been issued in the market with ID numbers (about 82% of 21 million BTCs). As of 2018, roughly every ten minutes on average, 12.5 BTCs were being issued with new IDs. This procedure of new issue is implemented as a reward for the first person/group to validate transactions without double spends that have been collected in a block. This is a competition of validation via computation, with the aim of solving a specific mathematical problem.[4] This computation is described as mining, and those who conduct mining are miners. The speed of new issue of Bitcoin on the register record is set to be halved every four years. At the beginning of the Bitcoin system in January 2009, the reward was 50 BTCs per ten minutes; it was halved to 25 BTCs per ten minutes on November 28, 2012. It remained the same reward per ten minutes until it was halved to 12.5 BTCs per ten minutes on July 9, 2016,[5] and this halving process will continue until 2140, when the new issue of BTC will be terminated. Total circulation of BTC will be fixed at a little less than 21 million BTCs.

There are differences between a real estate registry system and the Bitcoin system. In Japan, for instance, the real estate register record is kept exclusively by the Legal Affairs Bureau and the public is only allowed to read the record. In contrast, the virtual registry book that contains all information on Bitcoin transactions and ownership is maintained individually among participants. This decentralized nature of virtual registry bookkeeping activity may create some inconsistencies among participants. In the Bitcoin protocol, when an identical Bitcoin segment is used twice for different payments—leading to a Bitcoin segment having two branches (double spends)—the majority decision rule is used to determine which payment is genuine. To be more precise, the Bitcoin protocol authenticates a genuine Bitcoin registry book in which

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[2] The minimum unit of BTC is not 1 BTC, but it can be divided into $1/10^8$ units of BTC.

[3] In fact, settlement is made over (multiple) part of lots that can only be identified as quantities. But we believe that this metaphor by a real estate register record captures the essence of BTC trading.

[4] We will discuss this problem in detail in Sect. 6.2.

[5] Four years after January 2009 and November 2012 must be January 2013 and November 2016, respectively. The actual events seem to happen quicker than the original statement. This is due to the program that sets a reward to be halved in every 210 thousand BTC block extensions, i.e., a mining reward is halved not by calendar date, but by the block extension numbers. In Sect. 6.2, the meaning of block extension is fully explained.

a chain of blocks or *blockchain*, after branching, extends the longest.[6] The advantage of majority decision rule is to solve a deadlock situation in which two parties disagree with each other. However, as Eyal and Sirer (2013) argue, the majority decision is not enough to protect against collective selfish mining that commands more than one-third of the whole resources,[7] given the delayed finality confirmation structure we describe in the next section.

The bookkeeping method of ownership transaction is not restricted to a type of real estate registry system in which the ownership of each segment is recorded. Deposit account data in a banking system keep transaction and balance records for individuals; in Bitcoin phrasing, this is equivalent to the number of segments the deposit account holder has previously used and can currently use. The advantage of this method is that it allows the management of the large number of segments with a relatively small number of accounts.[8] The reason the Bitcoin protocol employs the real estate-like registry system, rather than the bank deposit-like account system, is probably because Nakamoto and his collaborators think that it is suitable for decentralized processing.

The Bitcoin protocol uses a hash value[9] of a beneficiary's public key as its ID number. A hash value is a sort of digest of original data, which is obtained after a designated calculation process by some specific algorithm (we will come back to this later). By using a hash value as an ID number, together with a public key itself, the Bitcoin protocol is able to maintain anonymity with as well as trustworthiness of trade.

[6] According to Nakamoto (2008), the system is supposed to authenticate the longest blockchain. In practice, however, the chain whose "total difficulty", which is the sum of difficulties to win the mathematical lottery associated with each block in the chain, is the greatest (therefore usually the longest chain) and prevails.

[7] Eyal and Sirer (2013) illustrates that Bitcoin's mining algorithm is not incentive-compatible, and that the Bitcoin ecosystem is open to manipulation, and potential takeover, by miners seeking to maximize their rewards. It points out that collective miners having more than as little as 33% of the total computational power (instead of widely believed 50%) can cheat the system with selfish mining and earn more than their fair share.

[8] For example, in case of ten-trillion-yen deposits by 1,000 million people, although it is possible to keep the ownership records of each yen, it may require very large computational and maintenance costs. Design of such a system is far more complex than a bank account-type of record keeping.

[9] A hash value is the value returned by a hash function that maps data of arbitrary size to data of fixed size. A cryptographic hash function is a one-way hash function, so that it is practically impossible to recreate the input data from its hash value. The same hash value will always result from the same data, but modifying the data by even one bit will completely change the hash value. In this chapter, the term *hash value* is used to denote the value returned by a cryptographic hash function. Bitcoin uses SHA-256 and RIPEMD-160 hash algorithms to generate identifiers from public keys, and applies SHA-256 twice to generate verifiably "random" numbers from a block in a way that requires a predictable amount of computational effort as described in Sect. 6.2.

6.2 Miners' Important, Exhausting Role

The essence of the Bitcoin protocol is its structure that guarantees the uniqueness of the segment information "registry book". This confirmation process broadly corresponds to one provided by the centralized payment system in the case of traditional banking. The Bitcoin protocol validates all transactions by means of open competition among profit-seeking miners as described above. This whole process is referred to as confirmation in the Bitcoin protocol.

The winner of the open competition provides the hash value as a stamp on the registry book, marking a validation of the trades in the specific block. At the same time, this winner receives newly created Bitcoin, and is recorded as the owner of such in the registry book. This process is called mining. In this chapter we distinguish the *confirmation* process in which all mining activities are involved from the *validation* process in which the winner of competition provides the hash value as a stamp on the registry book.

Miners play an important role in the validation of Bitcoin transactions which guarantees the uniqueness of the registry book. We call them miners because they are not a trusted third party that is assigned to prevent double spend events, but are voluntary participants seeking a reward from the open competition of validation. Only the winner receives Bitcoins in reward; all other miners receive nothing and must pay their mining costs. This is perhaps a cruel system from the viewpoint of miners.

This competition of validation is open every ten minutes on average. Trades collected by a miner before such ten-minute intervals form a block. After the validation, a new block is added to the existing blocks—a process called extending a blockchain. Newly created Bitcoins received as a reward for validation can be used for payment after a reasonably long blockchain is extended (i.e., long enough to prevent disputes over double spends).[10] The Bitcoin protocol employs a delayed finality confirmation structure in which Bitcoins cannot be used immediately after a transaction from the other party, even after validation of a transaction is made. This structure is quite different from the centralized payment system employed by the banking sector.

The Bitcoin protocol sets a variable difficulty of computation factor, to be solved by the miners in approximately ten minutes. When the miners' computation speed becomes faster (i.e., less than ten minutes on average), a parameter that determines a difficulty of computation is reset to make the block interval approximately ten minutes.[11]

[10] Bitcoins transferred between users can conventionally be used after 6-block extensions (about one hour later). Generated Bitcoins and transaction fees as a reward for a blockchain extension (we will discuss this later) can only be used after 100-block extensions (about 17 h later).

[11] This parameter adjustment is based on the algorithm for the Bitcoin protocol. The algorithm examines the speed of new-block creation in every 2,016-block extension (if one block is created in ten minutes, 2,016 blocks are equivalent to two weeks), and makes parameter adjustments.

This delayed finality confirmation structure is regarded as a weakness of the Bitcoin system from alternative cryptocurrency creators' points of view. However, there certainly exists a trade-off between approaching real-time finality and increasing risk in alterations of validated transactions.

Let us clarify the validation process in the Bitcoin protocol. This is a block extension process after confirming all past transactions:

(1) The hash value h_0 of the immediately previous block,
(2) The hash value q included in all transactions in the current block,
(3) Search for a value r that satisfies certain conditions, and
(4) New hash value h_1 is generated from three inputs (h_0,q,r). This new hash value h_1 is used as a validation stamp on the virtual registry book (see Fig. 6.1 for illustration).

In the Bitcoin protocol, h_0 and q are exogenously given (these figures depend on the past history of trades), and miners have to search r to satisfy the condition $h_1 \leqq t$ (target). This exercise is called the proof of work. The concept of proof of work comes from Dwork and Naor (1992) and Back (2002). They provide a computational technique for combatting junk mail and controlling access to a shared resource. Their main contribution is requiring a user to compute a moderately hard, but not intractable, function in order to gain access to the resource, thus preventing frivolous use. In the Bitcoin system, this concept is used to give confirmation of the transactions via the mining competition. In exchange the winner of the competition receives a reward. This incentive mechanism is the most innovative part of the Bitcoin system, and it works well.

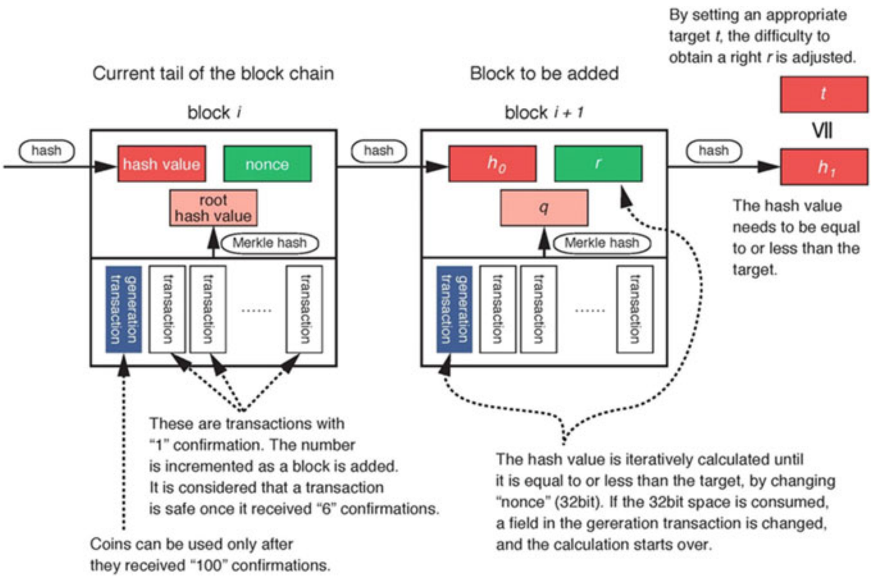

Fig. 6.1 Flowchart of the proof of the work

6.3 Proof of Work or Proof of Waste?

Let us clarify the meaning of the problem the Bitcoin protocol imposes on the miners. The problem is "to search x to satisfy the condition $h_1 \leqq t$ (target in 256 bits) where the hash value h_1 is generated from (h_0, q, x). Put solution x as r." If we do not impose any restriction on r (that is, $t = 2^{256} - 1$), any number would satisfy the problem. If we set t to be small, a probability of finding r in the hash function would drop sharply.[12] If the difficulty (as measured by parameter n) of this problem goes beyond a certain point, any standard personal computer cannot find a solution within a certain period of time (ten minutes in this case).

This implementation differs from the original design by Nakamoto (2008). The original design states that "to search a hash value $h_1$obtained form (h_0, q, x) whose first n bit is zero. Put solution x as r." In this design, a difficulty parameter n for the proof of work can be adjusted but allows only for a discrete change. The current design is superior and encompasses the original design.[13]

However, the original design by Nakamoto is intuitive. Note, in this chapter, we use t and n interchangeably since $t = 2^{256-\mathrm{n}} - 1$. Then,

(1) If n is zero, search value r, given h_0 and q, can be any value.
(2) If n grows gradually from zero, the probability to find a search value r becomes rapidly smaller (if n increases by 1, the probability gets halved).

By adjusting the difficulty parameter n, together with exogenous technological change and miner entry and exit, the speed of a block formation can be controlled. Parameters t or n enable the speed of block formation to stay more or less constant at ten minutes on average.

As is clear from the above discussion, a choice of parameter t or n in the proof of work depends on computational power, technological change, and the numbers of miners.[14] The impact of technological change is intuitive: if the computational power doubles, the difficulty of the problem must double: n must shift to $n + 1$. The impact of the number of miners is basically similar, but more important in practice as it is more likely the number of miners will double than would computational power.

Let us further elaborate upon the issues related to the proof of work. The essence of this issue is that we assume a miner's probability of finding a solution to some arbitrarily large number of calculations is independent even if there are reasonable numbers of miners. Let us assume the rare event of a miner's finding some r that

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[12] If r is any arbitrary number in 256 bit and the hash function used in this protocol can generate an ideally uniform random diffusion, the probability would be about $1/2^{256-\log_2 \mathrm{t}}$.

[13] The original design by Nakamoto allows selection of a number t such that $log_2 t$ generates an integer. The current Bitcoin protocol allows selection of any number for a difficulty parameter.

[14] Due to the characteristics of hash function in the proof of work problem, a number of trades in a block does not matter with n or t. If trades use some divisions or mergers of bitcoin segments within a block, the validation process could be a bit more complex although the calculation burden does not increase much. It is true that transaction fees are paid to the miners when such additional calculations are involved. A share of transaction fees in the miners' rewards is very small (see https://en.bitcoin.it/wiki/Transaction_fees).

satisfies the required conditions within a ten-minute interval is set to probability λ (provided all miners have the same computational power), and M miners participate in the mining competition, the probability of no miner finding r within an interval is given as $(1-\lambda)^{M}$, the probability of a miner's finding r within an interval is $1-(1-\lambda)^{M}$. We also assume that a probability of such a rare independent event follows the Poisson distribution. Then an average waiting time θ for such a rare event is an inverse of the probability of the event, thus $\frac{1}{\theta}$ is defined as $1-(1-\lambda)^{M}$. Approximating $\frac{1}{\theta}$ by the first-order Taylor expansion at $\lambda = 0$ leads to $\frac{1}{\theta} \approx M\lambda$, or

$$\theta \approx \frac{1}{M\lambda} \tag{6.1}$$

Miners try to find some number less than or equal to 2^{256-n} among 2^{256} possibilities. Consequently, the winning probability λ is proportional to $\frac{2^{256-n}}{2^{256}}$ at the coefficient of computational power K.

$$\lambda = \frac{2^{256-n}}{2^{256}} K \tag{6.2}$$

Substituting Eq. (6.2) into Eq. (6.1), we obtain

$$\theta \approx \frac{2^{n}}{KM} \tag{6.3}$$

The average time of a block validation (the average waiting time for the miner to find r) is determined as follows:

(1) It increases as difficulty n for the proof of work at the speed of 2^{n}.
(2) It decreases in inverse proportion to the number of miners M, and
(3) It decreases in inverse proportion to the computational power.

The difficulty parameter n for the proof of work was 32 in January 2009, raised to 40 by December 2009, raised to 62 by December 2013, and was 74 as of October 2018. These changes cannot be explained by increases in computational technological change but must reflect the fact that many new miners entered in mining competition.

These observations hint at the nature of proof of work as the core concept of the Bitcoin system. As shown above, difficulty parameter n has nothing to do with the quality of validation of a block. That is why n can be raised and reduced flexibly without affecting a validation process. That is, the proof of work is not an issue in maintaining the quality of Bitcoin, but is the cost to maintain a steady speed of new issues of Bitcoin (at the moment, it is 12.5 BTCs per approximately ten minutes). In order to evaluate the nature of proof of work, this role must be examined. If the role is properly carried out, it would be considered reasonable. Otherwise it would not be the proof of work, but it would be the proof of *waste,* because it would be a mechanism to provide rewards for the mining competition with excessively large computational cost.

It is essential for the Bitcoin system to provide an incentive for those who contribute to the maintenance of the system. In case of standard electronic money, an issuer of electronic money receives participation fees directly from the retail shops; they are paid not by the electronic money they issue, but by central bank notes. Central banks themselves pay maintenance costs and receive service rewards in the money they issue.

In the case of Bitcoin, the miner who contributes to the maintenance of the system receives Bitcoins as their reward, so it resembles the central bank system. A difference between the Bitcoin system and the central bank system lies in the fact that the former gives a reward to a miner who happens to win the mining competition while the latter receives a reward constantly. If there is a single miner in the Bitcoin system, r can be any arbitrary 256 bit value (n can be zero). In such a case, the competition mechanism that guarantees a validity of proof of work does not work and we require some alternative. If an alternative works, it could be sufficient to prevent double spends. This situation can be described as the mint model of cryptocurrency.

The mint model differs from the Bitcoin model in the sense that the former model uses a finality confirmation structure with legal enforcement, while the latter model uses a finality confirmation structure via mining competition. Note again that the winner of the competition is the only competitor to be rewarded with Bitcoin. The probability of winning a reward must be based on the proportional computational power of an individual miner to the total computational power of all mining participants: all miners may expect to receive rewards proportional to their computational power after a reasonable number of mining competitions.[15]

Then we must ask ourselves, can the proof of work contribute to the stability of Bitcoin value? Nakamoto (2008) states that "once a predetermined number of coins have entered circulation, the incentive can transition entirely to transaction fees and be completely inflation-free"(p. 4).

The answer is no. As Fig. 6.2 amply illustrates, the values of Bitcoin as measured in U.S. dollars fluctuate wildly compared with those of other foreign currencies. The reason for this high volatility is apparent. Demand for Bitcoin, regardless of the motivation for holding (i.e., payment or speculation), increases as its price decreases and vice versa. As Fig. 6.3 shows, the demand curve of Bitcoin, therefore, would be downward sloping[16] while supply the curve of Bitcoin at any point of time would be vertical. All demand shocks (such as E^* or E^{**}) must be absorbed in price adjustments (such as P^* or P^{**}).

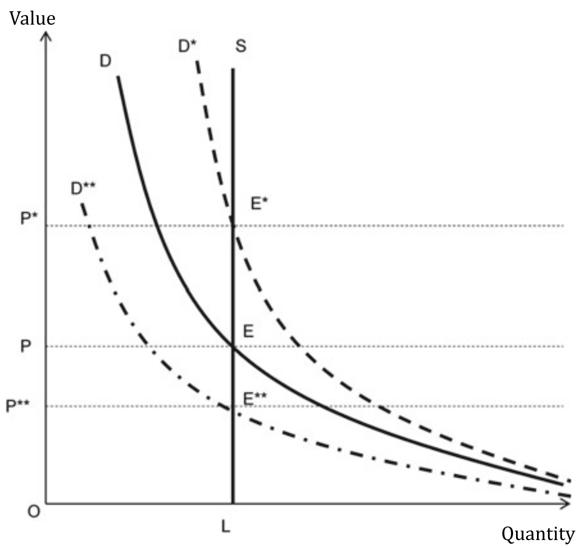
We note Bitcoin pricing differs from the pricing mechanism under the gold standard in two aspects. First, the supply of gold as natural resource must be adjusted to the marginal cost (i.e., the miner would set its production so as to make the market

[15] Of course, we need to consider how fair mining competition is. But if the loser with lower computational power would have no chance to win the competition, he or she would exit from the competition after several trials. In the long run, all competition participants must have more or less the similar computational powers.

[16] If people take into account Bitcoin prices and all news up to the previous periods and expect the current price appropriately, then they form their demand curve fairly close to horizontal (i.e., flat). We do not discuss such a case here.

Fig. 6.2 Market price of bitcoin in USD as of October 7, 2018, Source: blockchain.com

Fig. 6.3 Supply and demand of bitcoin: case of a vertical supply curve



value of gold equal to the marginal cost of gold mining). Secondly, gold can be used for industrial and jewelry purposes as well as for money. If the price of gold coins goes up, the gold used for industrial and jewelry would be converted to gold coins and vice versa.

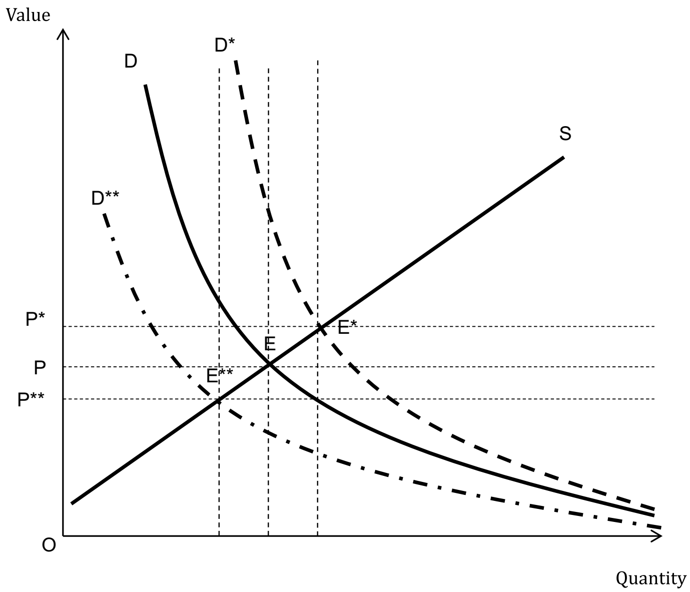


Fig. 6.4 Supply and demand of the gold coin: a case of an upward-sloping supply curve

Gold coins should consequently be expected to manifest an upward sloping supply curve. In this case, as shown in Fig. 6.4, demand shocks can be absorbed in both prices and quantities. Compared with that of Bitcoin, the price of gold coins would be consequently less volatile due to this supply elasticity.[17] The price volatility of Bitcoin may reflect a rather naïve understanding by the designers of the Bitcoin system that the monetary value of Bitcoin would be stabilized with a fixed money supply rule.

[17] Of course, the price stability of gold coin under the gold standard may not be attributable solely to the supply curve adjustment mechanism. As to the gold price stability in the late nineteenth century to the early twentieth century, Keynes (1924) argues "for when gold was relatively abundant and flowed towards them, it was absorbed by their allowing their ratio of gold reserves to rise slightly; and when it was relatively scarce, the fact that they had no intention of ever utilising their gold reserves for any practical purpose, permitted most of them to view with equanimity a moderate weakening of their proportion. A great part of the flow of South African gold between the end of the Boer War and 1914 was able to find its way into the central gold reserves of European and other countries with the minimum effect on prices" (pp. 166–167). The supply shocks of gold and silver discovery sometime cause volatility of the gold and silver coins. From 1550 to 1620, the prices in Western Europe as measured in silver coins increased 2.5 times (annual inflation rate about 1.5%) as a result of the new flow of silver from the American continent. This is called the price revolution period.

6.4 Dual Instability

Let us consider the miner's behavior from a broad cost/benefit analytic perspective. Miners voluntarily participate in the mining competition and invest in their computational power, and would exit if mining costs exceed its benefits. In principle, this situation of entry and exit is common to all industries. The only difference from standard industries is that supply of Bitcoin is independent from miners' entry and exit.

To elaborate upon this point, we divide the miners' computational power into M units. M varies according to miners' entry and exit. But the reward for the winner of mining competition is fixed as about Z per hour (at the moment, 12.5 BTC per ten minutes, Z would be about 75) regardless of entry and exit of miners.[18] Assuming that the Bitcoin protocol sets *n* properly, Z would be fixed for a length of an hour. This fact is reflected in the vertical supply curve of Fig. 6.3.

As we make two assumptions, (1) the winning probability is proportional to the computational power, and (2) the power is evenly distributed among M miners, the expected reward/benefit per unit per hour is Z/M. If the market value of Bitcoin is given as P, the market value of expected reward is PZ/M. We argue that this equals the marginal cost of mining (*mc*) at equilibrium.

$$mc = \frac{PZ}{M} \tag{6.4}$$

If the mining cost is lower than PZ/M, then the miners obtain net benefit/return, and vice versa. Let us reflect on these aspects in the past one year or so.

(1) If the market value of expected reward PZ/M exceeds the average cost of adding one unit (given exogenously by a technological change), the new entry would increase. But as M increases accordingly, the expected reward/return per unit (average productivity) would drop. Eventually the new entry would cease. This situation is a kind of equilibrium and remains until news on the Bitcoin price arrives. Good news, or Bitcoin price increases, induces the new entry, which continues up to the point where M equilibrates between the marginal cost and the market price. The problem occurs when bad news arrives.
(2) Assume bad news arrives when the Bitcoin system equilibrates. If bad news reduces the Bitcoin market price, the miners' net return would be negative. If the miners' computational power can be reallocated to other purposes, migration from Bitcoin mining would happen gradually. Accordingly, depending on the size of the decrease of M, the expected return per unit would recover. This situation could happen when the mining is conducted in the spare time of a mainframe computer. This can be described as the pastoral reality of early Bitcoin mining.

[18] We put "about" because the Bitcoin protocol set a time interval of a block 10 min on average by adjusting difficulty parameter *n*.

(3) The current reality is not pastoral at all, however. As Fig. 6.2 illustrates, the Bitcoin price shot up after November 2013.[19] This fact rendered the mining business very profitable. As a result, many entrepreneurs entered into the Bitcoin mining competition equipped with super powerful computers with designated IC chips.[20] The current situation resembles a heavy equipment industry in which it is easy to enter but is difficult to exit because of large sunk costs.

(4) Suppose that the Bitcoin price drops by a substantial, but not deadly, margin. To be more precise, it falls to some price lower than the average cost per unit but above the average variable cost. The miners would continue mining because it is rational to keep operations as long as return/revenue exceeds variable cost (i.e., total cost minus fixed cost); the eventual operational loss would be smaller than that incurred by immediate stoppage. According to some reports on Bitcoin mining, many large-scale miners who entered after the Bitcoin boom in late 2013 continue running their operations even with negative returns. They may not actively anticipate the return of above-1,000 dollar/Bitcoin days, but they might simply assume that eventual operational loss would be minimized by continued operation.

(5) Miners may also migrate to another mine in which they can continue mining, should computational powers be convertible to the new mine.[21] As we mentioned before, if the miners migrate to other mines, the size of M decreases and the expected return per unit would recover. By this mechanism, Bitcoin mining can survive even under a very volatile Bitcoin price. On the other hand, miners' computing equipment may reach the end of its useful life, and miners might have to stop mining before they recover all their sunk costs.

(6) Bitcoin mining might end another way. If the Bitcoin price drops sharply below the average variable cost, all miners would exit from mining. Many miners entered the Bitcoin mining competition after the Bitcoin boom in late 2013. Their computational power would be expected to be broadly similar.[22] If that is the case, the miners' exit strategy would not be a gradual one but could be

[19] The Bitcoin market price was about ten dollars in early 2013. It shot up above 1,000 dollars at the end of November 2013. It is hard to tell the exact reason for this. We cannot exclude a possibility of the bubble because the Bitcoin system tends to create a bubble as the supply curve stands vertically. If Bitcoin was used to transfer capital from Cyprus in case of a financial crisis in 2012–2013, the price hike of Bitcoin can be explained reasonably by this event. Suppose, if one Bitcoin is ten dollars, 100 million-dollar transfers from Cyprus require 10 million BTCs. That would exhaust almost all Bitcoins in the market.

[20] This movement is consistent with change in difficulty parameter n. As Eq. (6.3) indicates, an increase in n (from n to $n+1$) is equivalent to double the number of miners units M.

[21] Many alternative cryptocurrencies to Bitcoin have emerged recently. If the operational protocol is closer to that of Bitcoin, it would be much easier to convert their mining operation into the new cryptocurrency. There already exists a service to provide relative mining profitability among alternative cryptocurrencies so that the miners can move around the profitable mines.

[22] Most calculation in the Bitcoin mining is allocated to searching for the value r to solve the problem. This calculation is made by the Bitcoin mining dedicated IC chips (ASIC). Computational power is proportional to the numbers of ASIC. We suppose the productivity of miners in terms of computational power per unit is more or less equal.

sudden. If the Bitcoin price drops below a threshold, the Bitcoin system as a whole may collapse or the Bitcoin users are limited to a very small number of inner members with which Bitcoin is exchanged at a very small scale. Once all miners leave Bitcoin mining, no one would be engaged in the proof of work. A validation of a block would be delayed or stopped, and in consequence Bitcoin would cease to be a useable currency. This type of risk does not exist in gold mining.[23]

From the above observations, it is clear that the Bitcoin system intrinsically manifests dual instability. The first instability stems from an inflexible supply curve of Bitcoin, which amplifies Bitcoin price volatility; the miners' revenue/reward fully absorbs any price changes. There is no price stabilization mechanism. The second instability comes from risks to the sustainability of mining. During a Bitcoin price boom, miners engage in mining activity which guarantees the supply of Bitcoin. But during a Bitcoin price depression, no smooth way to induce exits from mining exists.[24] The current situation of the Bitcoin system can be interpreted as a freezing equilibrium with dual instability. See Fig. 6.5 as share of mining pool as of October 7, 2018.

6.5 Monetary Policy Without a Central Bank

Cryptocurrencies like Bitcoin do not depend on a central bank. With some amendments to its design, we can use this cryptocurrency (we call this currency, an extension to Bitcoin, *Improved Bitcoin,* or IBC) to implement some equivalent policy effects as a central bank conducting monetary policy. It is indeed *monetary policy without the central bank*. To do so, we need to conquer the dual instability issues discussed in Sect. 6.4.

6.5.1 Currency Boards as Inspiration

A simple and straightforward currency supply rule is that—given the market value/price of IBC vis-à-vis the U.S. dollar or the Euro as a benchmark—if the market value of IBC increases, the system would issue IBCs until the market value returns to the benchmark level. This rule can be described as the pegging rule of exchange rates, or the currency board system.

[23] This fact indicates that Bitcoin is not necessarily a cheap payment tool. We have to realize that Bitcoin has an externality. We will come back to this in Sect. 5.5.

[24] Once the price falls to the level that is lower than the average cost per unit but above the average variable cost, one solution for the miners is to sell their computers to other miners. But this action might induce a sharp drop in the price of Bitcoin mining-dedicated IC chip. That, in turn, would make exit more difficult. This could be the worst scenario for the miners.

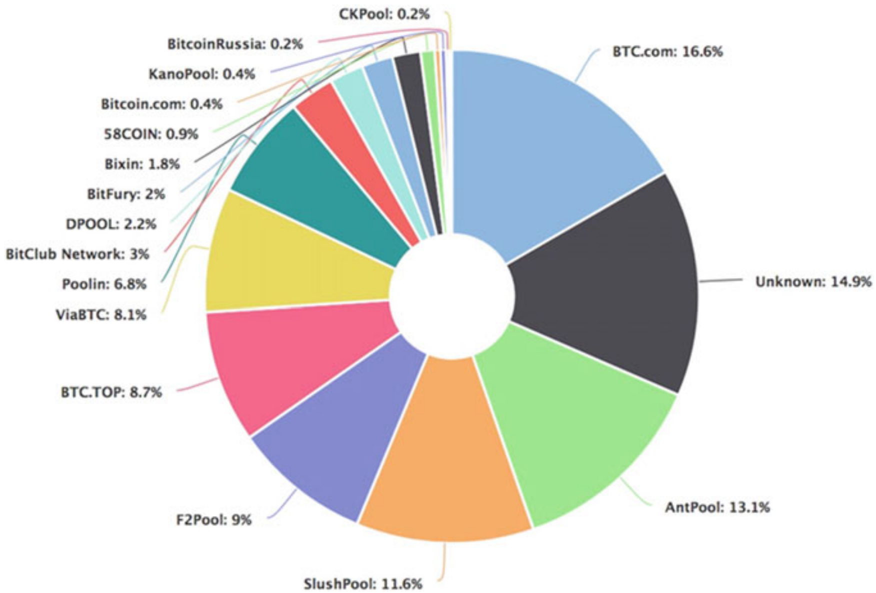


Fig. 6.5 Share of mining pool as of October 7, 2018. *Source* blockchain.com

To be more concrete, suppose the market value/price of IBC is P dollars at the moment. A reward for the proof of work V is set to rise when the market value P is above the benchmark value, and a reward V is set to be zero when P is below the benchmark. Alternatively, some difficulty parameter n, adjusting the speed of proof of work, is to be changed. In this case, without changing V, the quantity of new issue of IBC per hour Z is adjusted, because the expected waiting time$\theta$is affected by n, and Z is given as follows.

$$Z = \frac{V}{\theta} \tag{6.5}$$

In theory, both rules affect the market value of IBC equally. The above discussion can be a starting point to consider the market value stability of a cryptocurrency. In the Bitcoin type of cryptocurrency, without a central authority, the policy framework for market value stabilization must be rule- rather than discretion-based.

This method has a serious defect: to reduce the new issue of IBCs to zero is not equivalent to absorbing excess IBCs in circulation. Figure 6.6 illustrates the kinked supply curve of IBCs, with current point E as a refraction point (for simplicity, let us assume supply and demand equilibrates at E). A positive demand shock to IBCs (increase in IBC demand) can be absorbed by shifting the supply curve from L to L^*. A negative demand shock to IBC (decrease in IBC demand) cannot be absorbed because the supply curve is vertical in this case. Consequently, the market value of IBC drops to P^{**}.

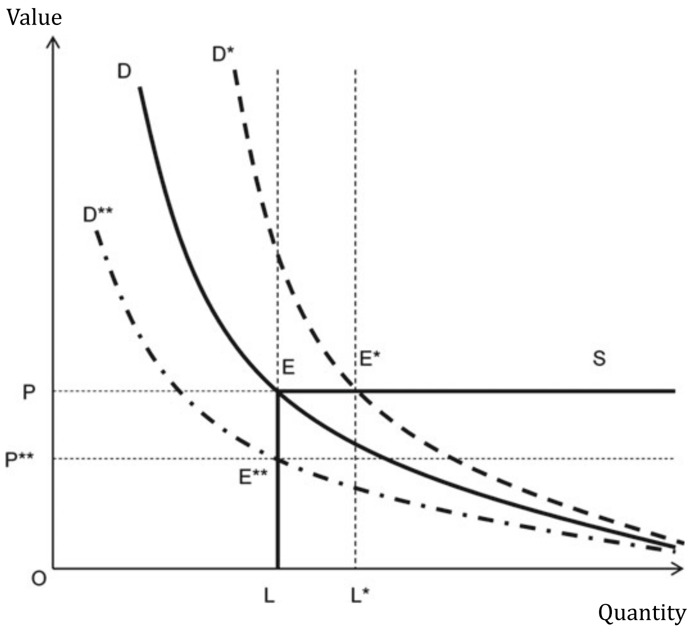


Fig. 6.6 Supply and demand of improved bitcoin: the case of a kinked supply curve

The supply of central bank notes can easily expand and contract. For a positive demand shock to bank notes (shifting from consumption/investment to money: it is a deflationary shock), the central bank increases money supply by buying securities and foreign currencies. For a negative demand shock to bank notes, the central bank absorbs money in circulation by selling securities and other assets. In the case of IBC, the latter operation is not included in its protocol. That is to say, the cryptocurrency protocol usually includes the currency supply rule but does not have a currency absorption or write-off protocol. Can we reduce this irreversibility?

6.5.2 Built-In Revaluation Rule for the Exchange Rate

It is the irreversibility of cryptocurrency supply that concerns us most, perhaps because of our obsession with understanding currency supply in terms of numbers. If we try to control currency quantities in terms of real purchasing power, it may not be so difficult to absorb surplus currencies in circulation. It is possible to include an inflation rate in the supply rule to amend irreversibility of currency. Here, an inflation rate is defined in terms of not P, but 1/P. If our basic idea is closer to a currency board, this amendment is an amended currency board with the built-in revaluation rule for exchange rates.

Our proposed amendment uses the market value of IBC, P, vis-à-vis the benchmark price as policy indicator to control our policy instruments V, Z, and *n*. The amendment uses the market value P with inflation rate α, i.e., $P^{*}\exp(\alpha\tau)$ as a policy indicator to control policy instruments V and *n* (τ is time periods since the starting point). With this rule, we can virtually absorb excessive currency or purchasing power in circulation due to currency demand shocks or policy mistakes. That is, we may not be able to eliminate currency in circulation but we can reduce its real value by allowing inflation.

How can we determine inflation rate α? It is clear that a higher α is more effective at absorbing demand shocks. Figure 6.7 illustrates this situation. The horizontal axis is converted quantity, rather than (currency) quantity. Converted quantity measures the real purchasing power of IBC in terms of benchmark currency. With higher α, real purchasing power at the moment shifts from L to L^{**} and the equilibrium point also shifts from E to E^{**}. As a result, if a demand shock shifts the D curve to a D^{**}curve, the supply side absorbs this shock and stabilizes the market value/price accordingly.

However, it is not necessarily true that higher α is better. Higher α implies that monetary value depreciates quickly. With higher α, people would avoid holding IBC per se. If the IBC system maintains a delayed finality confirmation structure like the Bitcoin system, participants must hold IBC in their wallet for a while after receiving IBC as their reward for mining or in exchange for the transaction of goods and services. It would be painful for IBC holders to see such depreciation during their hoarding period.

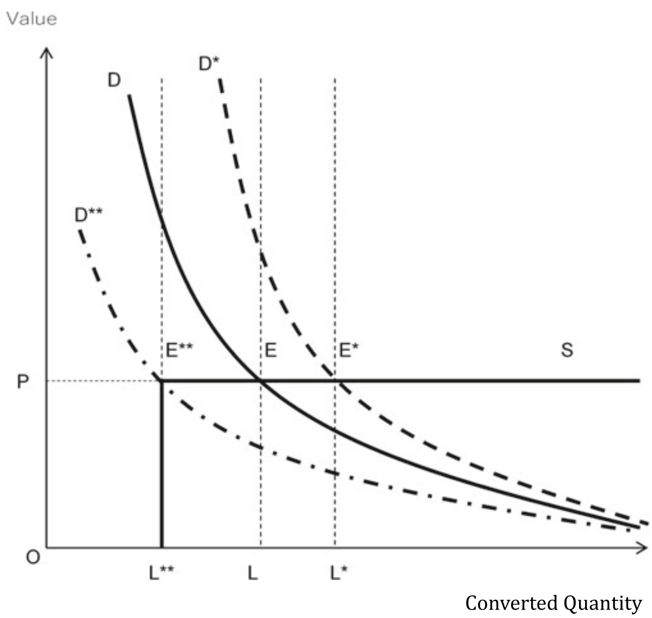


Fig. 6.7 Supply and demand of improved bitcoin: the case of an amended supply curve

In order to make our built-in revaluation rule practically workable, it may be better to separate the IBC operation rule from the benchmark price vis-à-vis the U.S. dollar. To do so, we need to investigate an intrinsic value for IBC.

6.5.3 Monetary Policy Without a Central Bank

The first task is to construct an IBC supply rule that can absorb a positive demand shock. In our discussion in Sects. 5.1 and 5.2, we said that if the IBC system can adjust supply proportional to computational power, the market value/price of IBC would rise and new miners would participate in IBC mining. For the long run we can construct an IBC supply schedule similar to Fig. 6.6. Here the demand and supply adjustment presumes new entry of the IBC miners.

Recall in Sect. 6.3 we obtained the following result, $\theta \approx 2^n/KM$. The current Bitcoin system adjusts difficulty parameter n to stabilize an average waiting time θ as the number of miners M increases. What will happen if n is not adjusted to an increase in M? From Eq. (6.3), θ will shrink inversely proportional to M. If a reward for the proof of work V is fixed for a block formation, new IBC issue per hour (Z $=$ V/ θ) would go up or down depending on M. If θ becomes too small, n could be raised (i.e., n $+$ 1 would double θ) or alternatively V could be doubled. In allowing for the duration of a block formation θ to shorten as M increases, a duration of finality confirmation would also shorten. That has merit, but, at the same time, the risk of admitting double spends increases.

Now the IBC system has acquired a built-in revaluation mechanism.[25] It is the first step toward monetary policy without a central bank. The monetary value of IBC with such a rule will be far more stable over time: an upward change in price induces new entry of miners up to the point where the marginal cost becomes equal to the reward measured in the price of IBC.

6.5.4 Implicit Inflation Target in Cryptocurrency

As discussed in Sect. 5.1, the IBC system can accommodate a positive demand shock (i.e., an upward change of price or a deflationary shock). This system cannot react properly to a negative demand shock (i.e., a downward change of price or an inflationary shock). Is there any remedy for this?

The answer is to set a structure that makes the IBC mining cost (which determines the market value/price of IBC) to gradually decrease over time. To be more precise, a reward V for a block formation increases at a designated growth rate of β. Together

[25] Allowing for these amendments, the IBC protocol has to be completely changed. For example, due to the alteration of supply rule, the total amount of IBC supply should be infinite. Duration of a block formation can be variable.

with a technological change rate γ,[26] the IBC mining cost per hour decreases at the rate of γ; market participants expect inflation at $\beta + \gamma$ per hour and the real value of IBC would drop. Its mathematics is as follows. Substituting Eqs. (6.5) and (6.3) into Eq. (6.4) leads to

$$\frac{1}{P} = \frac{1}{mc \cdot M} \frac{V}{\frac{2^n}{KM}} = \frac{V}{mc} \frac{K}{2^n} \tag{6.6}$$

Suppose that the computational power K and the difficulty parameter n are fixed, that the marginal cost mc decreases at the gross rate of γ thanks to a technological progress where $mc_\tau = mc_0 \exp(-\gamma\tau)$, and that the reward per block formation grows at the gross rate of β where $V_\tau = V_0 \exp(\beta\tau)$. Then, the price level of Bitcoin $\frac{1}{P}$ inflates at the net rate of $\beta + \gamma$ where $\frac{1}{P} = \frac{V_0}{mc_0} \frac{K}{2^n} \exp((\beta + \gamma)\tau)$.

As long as a negative demand shock reduces IBC demand within the range of IBC value depreciation, we can avoid unexpected IBC inflation shocks.

From Fig. 6.7, the point L** is the real IBC purchasing power discounted by expected inflation. L-L** is depreciation of purchasing power. If a negative demand shock falls in the range between D and D**, such a shock can be absorbed perfectly. Taking inflation expectation in the IBC valuation into account, an inflationary shock via monetary policy can be offset.

We note this rule is closely related to the inflation targeting policy implemented by many central banks. Inflation targeting is effective in softening an unexpected inflation shock.[27] The current rule has the same effect. We may call this rule an implicit inflation target for cryptocurrency. This rule, however, is different from inflation targeting by the central banks, in that their inflation target depends heavily on expectations formation by the public, and credibility of the central bank in general and the governor in particular. Both do not necessarily have strong linkages with the real economy, and as a result, their effects are sometimes vague and usually controversial. Our rule, on the contrary, depends on an economic principle, i.e., the cost structure of the mining that is real economic activity.

6.5.5 Another Demerit and Another Merit of Bitcoin as Currency

We have analyzed the Bitcoin system in general and the role of mining as the proof of work. We've proposed an alternative to Bitcoin, Improved Bitcoin (IBC), that is supposed to overcome the inherent instability of Bitcoin. But can IBC compete with major currencies issued by major central banks? In this section, we note one of many possible problems with such cryptocurrencies.

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[26] As technological change increases K, the computational power, IBC supply per hour will increase through shortening θ. We assume the technological change rate γ is exogenously given.

[27] For detailed discussions, see Iwamura and Watanabe (2006).

Cryptocurrencies are more expensive to produce while they cannot be absorbed once produced. The production costs are hard to retrieve. Bank notes issued by the central banks require some printing and material costs. These costs are negligible compared with the face (nominal) value. Also, bank notes are reversible between new issues and absorption because the central bank basically buys and sells securities with bank notes.

These points are fundamental shortfalls of cryptocurrency. As currently described, cryptocurrency values are based on associated production costs. This mechanism is similar to commodity money, notably gold and silver coins. Historically gold and silver coins have been replaced by credit (or fiat) money basically because of the above-mentioned points.

Shall we choose bank notes or a cryptocurrency? There is no unconditional answer. Bitcoin-type cryptocurrencies, with some amendments, can be reasonably competitive with central bank notes in terms of value/price stability. Currency competition in the sense of θ Friedrich A. Hayek (1976) is desirable. Such competition must be encouraged, not only between central bank notes and a cryptocurrency, but also between central bank notes and among different crypto-currencies.

The key differentiation of Bitcoin from central bank notes and existing digital cash-type electronic money is a framework in which all vintage information of each segment of Bitcoin is recorded.[28] Not many people are aware of this useful feature of Bitcoin. If this feature is introduced in bank note-like electronic money, each atom of bank note-like electronic money with its vintage information can reflect time value, i.e., each note is priced differently according to the time passed since its issuance. In other words, we can provide interest with each note. This system implies that owners of bank note-like electronic money can receive interest or pay some penalty, depending on economic conditions. In the current central banking system, these benefits are transferred to the government as seigniorage. Note that the monetary interest rate, as measured a unit of money today, is how much the same amount is anticipated to be worth one year from now. It is different from a nominal interest rate that is a return from investment of zero interest-bearing money.[29]

If the legal system permits, this bank note-like electronic money can provide a substantial business opportunity. Strangely, the current generation of central bankers do not pay a lot of attention to the associated opportunities: to expand the flexibility of monetary policy by converting from paper money to bank note-like electronic money with vintage information. With this framework, central banks are no longer

[28] In practice, when Bitcoin is issued, all vintage information is recorded. After some transactions, divisions and merges are repeated so that original vintage information can no longer carry over. A design of electronic money that can keep all vintage information cannot be used in the Bitcoin system as it is now. We suppose there is a way to maintain all vintage information even after repeated transactions. It is an important research question.

[29] Gesell (1918) advocated the idea of stamped money. His idea is used in some regional moneys now. Alas, most of these moneys are employed only in the region of negative interest rate (i.e., penalty charge). It is also worthwhile pointing out that Keynes (1936) spares his Chap. 23, Sect. 6, to discuss and evaluate Gesell's idea of stamped money positively.

vulnerable to Keynes' (1936) liquidity trap, by avoidance of the zero lower bound interest rate.[30]

6.6 Conclusion

Why did Bitcoin not exist until recently? Decentralized money provision, and similar economic systems with peer-to-peer (P2P) technology, were proposed well before Bitcoin, but these trials failed to grow like Bitcoin. Perhaps early challengers may have taken the nature of money and autonomy of economic activity too seriously.

The major drivers behind Bitcoin's success are (1) a naïve understanding of currency, (2) the employment of an easy-to-understand asymmetric key cryptosystem for validation of transactions and a virtual register system, and (3) the creation of a participatory system with a P2P network maintained by the elliptic curve digital signature algorithm and a hash function. This framework has attracted many programmers and collaborators to improve user software and that, in turn, attract many users of Bitcoin.

In addition, the originator of Bitcoin–Satoshi Nakamoto—and his collaborators demonstrated they can create a currency without a central bank via proof of work, and that there exists a demand for such a currency.

A unexpected feature of Bitcoin is that, contrary to the original belief of Satoshi Nakamoto et al. that they can create currency without inflation by means of controlling and preannouncing a total supply of Bitcoin, the market value/price of Bitcoin fluctuates up (deflation or the value of Bitcoin goes up) and down (inflation or the value of Bitcoin goes down). We hope that Nakamoto's important contributions can nullify their misunderstandings. We are grateful to him for the imperfect Bitcoin innovation. There remains much room for improvement and for discussion of our future monetary system.

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[30] It is possible to add vintage information to the current paper money by printing the issue date. It would be far more troublesome to handle each note differently. If in the case of digital currency, that problem can be solved easily.

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Chapter 7
A Cashless Society: Facts and Issues

7.1 Introduction

In this chapter, I would like to describe my views on the development of a cashless society. We will first examine statistics related to cashless payments. The cashless payment ratio presented by the Japanese government represents the ratio of the amount paid with credit cards, electronic money, and debit cards to the amount of private final consumption expenditure, and it has been pointed out that the value of this ratio in Japan was 18.2% in 2015, which was quite low among developed countries. However, this statistic does not include bank transfers/account transfers and other electronic payments that households and businesses use on a daily basis, and is not considered to be a useful statistic when considering a cashless society. When recalculated to include bank transfers/account transfers, the cashless payment ratio reaches as high as 92% in Japan, which is not a low figure even among developed countries.

With regard to the choice of payment method, empirical studies and observed facts indicate that the cost structure is much more complex than the cost function considered by economic theorists, and that there are differences among retailers in their attitudes toward pricing and discounts. It is also clear that retailers have different attitudes toward pricing and discounting, and that the fact that cash payments are still used to some extent may reflect the preferences of retailers as well as consumers.

With regard to the merits of going cashless, most of the issues discussed are based on the assumption that cash will be abolished, and do not identify the advantages of going cashless while maintaining cash. At the same time, the disadvantages also relate to special cases where cash payments are rejected and the scale and immediacy of crime in cyberspace compared to cash, and do not discuss the disadvantages created by cashlessness itself.

As for policy issues, we discuss measures that will lead to the realization of a cashless society, including the creation of a system and the fostering of a competitive environment for businesses to increase the quality and diversity of their payment methods, and the promotion of digitization, with the government taking the lead.

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The interpretation here is that a cashless society will emerge as a by-product of the industrial revolution that has been underway since the end of the twentieth century, centered on the development of information and communications.

7.2 Statistics Related to the Cashless System

Among some statistics that capture the reality of cashless payments, we discuss two indicators that we felt needed to be explained.

7.2.1 Cashless Payment Ratio

The Ministry of Economy, Trade and Industry's "Fin Tech Vision" defines the cashless payment ratio as the amount of cashless payments (payments made with credit cards, debit cards, and electronic money) as a percentage of private final consumption expenditure. In Japan, the ratio was 18.2% as of 2015, which is quite low, and the government set a numerical target (Key Performance Indicator: KPI) in its Future Investment Strategy 2017 to raise the ratio to around 40% over the next 10 years.

The figures and future numerical targets for the cashless payment ratio have been circulated through the mass media and other media, and there is a widespread perception that Japan is a cash-based society compared with other developed countries. However, we consider the progress of cashless society not only in terms of the quantitative aspect, such as the increase in the ratio of cashless payment methods used, but also in terms of qualitative improvements, such as the addition of new value that contributes to user convenience and the provision of payment methods at lower prices than in the past. Also, as Fuchida (2018) writes, the cashless payment ratio set as a KPI in the "Future Investment Strategy 2017" ignores traditional electronic payment methods such as bank transfers, automatic deductions, and account transfers, and it does not include inter-personal transfers between mobile phones or Payment Initiation Service Provider (PISP)-type payments are also not considered. In order to take these points into account, we proposed to add the share of bank transfers/account transfers in private final consumption expenditure.

However, it should be noted that transfers/account transfers include direct debits related to the use of credit cards and so on, thus simply adding them up may result in double counting. Here, we assume that all credit card payments are included in transfers/account transfers, and recalculate the ratio of cash and cashless payments, which were 8 versus 92% in 2015 data. This means that electronic payments accounted for 92% of the total, while cash payments accounted for less than 10%. At the same time, a recalculation of the same data for Germany, which was identified as having a lower cashless payment ratio than Japan, showed a ratio of 2.58 to 97.42%. According to this definition, Germany was even more cashless than Japan. Interestingly, the same recalculation for Singapore, which had the highest cashless payment ratio, showed that the ratio was 16.52 versus 83.48%, indicating that Singapore was lagging behind Japan and Germany in cashless payments. As for South Korea, which had a high cashless payment ratio of 90%, the ratio was 0.43 versus 99.57%, which means that the country had almost completely achieved cashless payments. This seems to be an overestimation of cashlessness, given the realities in South Korea. Furthermore, I think it is a matter of national accounts in China; the amount of credit card payments is more than twice as large as private final consumption expenditure. Whether this is because credit card payments include payments other than private final consumption expenditure or because private final consumption expenditure is underreported, cannot be determined for China, which is often mentioned as a country that is making progress in going cashless, strict international comparisons using statistics should be avoided (see Nakajima, 2017).

According to the Committee on Payments and Market Infrastructures (CPMI, 2016, 2017) in BIS, the cashless payment ratio in Japan appears to have increased steadily from 14.3% in 2011 to 18.2% in 2015. However, if we recalculate the ratio to include bank transfers and direct debits, the ratio remains almost unchanged at 8.48 versus 91.52% in 2011.

So what is the reality? To give an overview of the flow of funds in the household sector in Japan, including my personal experience, most salaries and other income are paid by bank transfer. From this, monthly expenditures are made, but the majority of housing, utilities, transportation and communications, and education are paid by direct debit. Durable consumer goods such as clothing, footwear, furniture, and household goods are also likely to be paid for by credit card or other means of payment rather than cash. The only areas of household consumption that are likely to be paid for in cash are food, education and entertainment, health care, and others. The total share of these items is estimated to be about 50% of total expenditures at most.

As will be discussed later, the choice of means of payment differs according to the range of payments, with credit card payments and bank transfers/direct debits being chosen for high-value expenditures exceeding 10,000 yen, and electronic money being used more frequently in recent years for payments of 1,000 yen or less. Taking these factors into account, there is still a possibility that cash will be used for payments in the range between 1,000 yen and 10,000 yen. It is not surprising to consider this to be about 10% of total household spending.

In summary, the government's statistic that cash spending accounts for 80% of private final consumption expenditure, including households, does not reflect reality, and although individual differences may exist, it is thought that cash spending is at most 10%, with the remaining 90% being paid electronically.

This chapter is not interested only in retail payments in Japan, but also in trends in private (household and corporate) payments in the Japanese economy as a whole and the financial system's response to these trends. In particular, when considering the financial system's response, it is desirable to consider the entire payment system, including bank transfers and account transfers as an issue.

7.2.2 *Ratio of Cash in Circulation to Nominal GDP*

According to Bank of Japan (2017), the ratio of cash balances in circulation to nominal GDP was 19.4% in 2015, the highest among the CPMI member countries. The Bank's explanation for this high cash balance is as follows. (1) The demand for cash as a means of storing value is quite high, reflecting the high level of security in the country, the low level of counterfeit currency, the high level of public confidence in banknotes, and the low opportunity cost of holding cash due to low interest rates. (2) Cash is generally accepted as a means of payment. This is because cash is valued for its various characteristics, such as compulsory acceptability, general acceptability, finality, and anonymity.

As is a common problem in economics, it is impossible to explain economic variables that change over time with constant institutions and characteristics. Please see Fig. 7.1. In 1994, the ratio was 9.26%, which is not very high by international standards. It is not likely that the institutions and characteristics used by the BOJ to explain the ratio in Japan doubled between 1994 and 2016. It is unlikely.

Rather, the background here is probably that the Bank of Japan has continued monetary easing almost consistently and has increased the supply of currency (base money) at a pace faster than the rate of economic growth. I think there is a problem in linking this statistic to trends in the demand for currency by the private sector, including households, and the resulting slump in cashless payments.

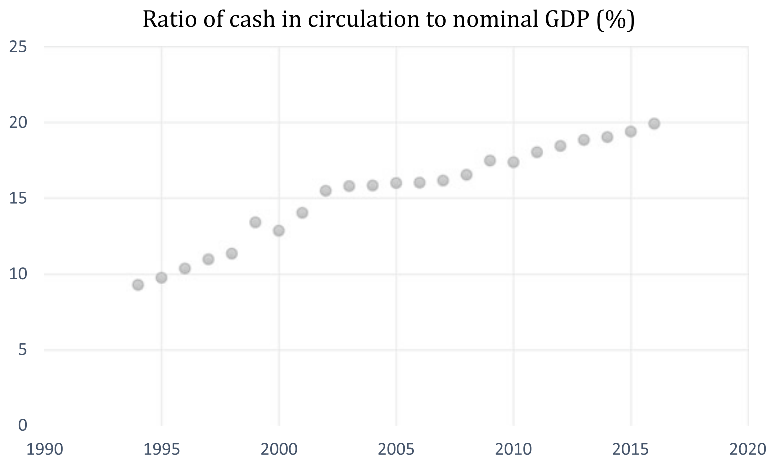

Fig. 7.1 Ratio of cash in circulation to nominal GDP (%)

7.3 Selecting a Payment Method

7.3.1 From the Results of Empirical Research

The choice of payment method depends on the size of the payment, and the main payment method is selected according to the size of the payment, as was established in an accumulation of theoretical and empirical studies in this area to date: Kitamura (2005, 2010); a series of studies by the Bank of Canada (Bagnall et al., 2016; Kosse et al. 2017; Wakamori et al., 1998; Shy, 2001), and Garcia-Swartz et al. (2006a, 2006b). Specifically, cash or electronic money is used for small payments of 1,000 yen or less, cash or debit cards for payments of 1,000 to 10,000 yen, credit cards for payments of 10,000 yen to 50,000 yen, and bank transfers for payments of 50,000 yen or more. In terms of the scale of retail outlets, sales of 1,000 yen or less are mainly at convenience stores and station kiosks, sales of 1,000–10,000 yen are mainly at supermarkets and individual specialty retailers, purchases of 10,000–50,000 yen are at department stores. For purchases of more than 50,000 yen, it would be high-end consumer durables specialty stores and high-end service stores. Each retailer already offers a payment method that matches its own payment range. In other words, convenience stores and kiosks offer electronic money such as Suica, WAON and nanaco; supermarkets offer credit cards with low annual fees; and department stores offer membership cards with credit card functions that charge a modest annual fee and provide extensive customer service.

If the cashless society is to be further advanced, the remaining areas of cash settlement will be (1) substitution of electronic money and debit cards for payments of small changes of 1,000 yen or less, and (2) substitution of credit cards, debit cards, and electronic money for payments at supermarkets and specialty retailers of between 1,000 yen and 10,000 yen.

In fact, in this field as well, supermarket e-money has expanded its charge limit to 50,000 yen and is building a system capable of handling payments of 10,000 yen or less. In addition, Suica and PASMO, which are transportation-related e-money, are working to expand the range of settlement amounts by issuing higher-end cards with automatic balance recharging and credit functions.

As shown in Chap. 5 (originally in Kitamura et al., 2009), the frequency of use of small coins such as 1 yen and 5 yen is steadily decreasing with the advent of electronic money, and a coinless system for small coins is under way.

A series of empirical and simulation studies conducted by the Bank of Canada has shown that consumers have a preference for cash that cannot be explained by various costs. So what other factors might be at play here?

7.3.2 Incentives for Choosing Payment Methods

When looking at settlement costs, what is often overlooked are the points given to electronic money and credit cards. From a common sense perspective, this is a return for the savings in management, accounting, and transportation costs associated with cash when using electronic money or credit cards, and at the same time, it is part of a strategy to attract customers by giving them an incentive to continue using electronic money or credit cards. It is also thought to be part of a strategy to attract customers by giving them an incentive to continue using electronic money and credit cards.

On the other hand, credit cards also require retailers to pay a fee, so some offer discounts for cash payments. There are still some long-established sushi restaurants and traditional Japanese cuisine restaurants that only accept cash payment. It is still there.

In this way, the incentives for choosing a payment method vary and do not seem to have a structure that can be statistically lumped together. In addition, the idea that it is desirable for retailers to offer a variety of payment options to acquire customers is not necessarily an accepted idea.

Although bank transfers and account transfers are widely used, they should be available 24 h a day, 365 days a year for convenience, but this is not yet the case in Japan. The 24-h operation of ATMs is also common practice overseas, but this is also not available in many places in Japan.

In the past, banks were not allowed to issue credit cards, but their affiliates issued credit cards in cooperation with credit card brands (Visa, MasterCard, etc.). Even today, when banks are able to issue credit cards, they do so in cooperation with the major credit card brands. As a result, credit card operations and management decisions are based on the judgment of the credit card brands, and may not necessarily be in line with the realities of the Japanese retail industry. The number of credit cards issued in 2017 was 272.01 million, a penetration rate of about 2.6 cards per adult. The conditions for issuing (or obtaining) a credit card in Japan are considered to be looser than those in other countries, and the use of credit cards is increasing. The use of debit cards is limited due to the fact that the number of stores where they can be used is still small and the hours of availability are restricted.

Electronic money cannot be used internationally because it cannot be withdrawn in cash (only one-way charging of cash to electronic money) and its specifications are different from those of foreign electronic money. Cross-border payment is the issue of e-money and Central Bank Digital Currency (CBDC) to be determined in the near future. From the point of view of foreign travelers, there is also the inconvenience of not being able to use the e-money in Japan that they use in their home country.

As described above, the choice of payment method is not necessarily made under the same conditions, or on equal footing. As mentioned, there is a segregation of payment methods according to industry and payment scale, and it can be judged that cash payment is selected to some extent among them.

7.4 Advantages and Disadvantages of Going Cashless

A problem that sometimes arises in the implementation of economic policy is that in calculating the merits (benefits) and demerits (costs) of a policy, the merits are overestimated and the demerits are underestimated, only to realize the magnitude of the actual demerits after the policy is implemented.

The immediate prospect of a cashless society does not envisage a society in which the circulation of cash currency is completely eliminated. Many of the advantages of a cashless society that many commentators have highlighted, consciously or unconsciously, emphasize the cost-saving effects that would result if cash currency were completely abolished. Naturally, while maintaining cash currency, as we saw in Sect. 7.2 of this chapter, the policy goal is to reduce cash settlements from about 8% of total settlements to about 4%, and if private final consumption expenditure is set at 286 trillion yen in 2016, 4% of that is about 11 trillion yen. In other words, we should discuss the merits and demerits of shifting 11 trillion yen worth of cash payments to electronic payments. There is not much to be gained by discussing the issue too broadly, however.

7.4.1 Advantages of Going Cashless

Fuchida (2017, 2018) and *Nikkei* MOOK (2018) enumerate the benefits of going cashless.

(1) No cost for production and maintenance of coins and banknotes.
(2) No cost for transportation and storage of cash.
(3) Eliminates the hassle and cost of anti-counterfeiting measures.
(4) Eliminates the public health problem of using coins and paper money.
(5) Enables faster and more efficient transactions.
(6) No need to queue up at a financial institution or ATM to withdraw cash.
(7) Eliminates cash-related costs for financial institutions such as investing in and managing ATMs.

Fuchida also discusses the benefits that will ripple throughout the economy.

(8) Shrinking the underground economy, criminal and terrorist financing, and tax evasion.
(9) Promoting financial inclusion.

Of these advantages listed, (1), (2), (3), and (4) can be achieved if cash is completely abolished, but they do not apply as long as cash currency continues to be issued. As for (2), if the demand for cash declines and the amount in circulation decreases, the cost may be reduced accordingly. The extent to which the number of ATMs and the vehicles to transport cash will be reduced will depend on the amount of the decline in demand. As for (4), currencies are more contaminated by mold than usually thought, and the risk of a pandemic would decrease if the use of currencies declined. Japanese currency is updated relatively frequently, and I have not heard of any cases where it has served as a vector for epidemics.

One of the arguments for (5) is that it eliminates the need to exchange cash and the need to confirm and count amounts. In terms of finality of payment, there is no quicker means of payment than cash payment. Electronic payments, even with debit cards, are slower than hand-delivered cash. It is true, nonetheless, that the time and effort required to confirm and count cash can be reduced if electronic payments are used. The point in (6) is that travel time and waiting time can be eliminated. Even with electronic payments, it takes time to operate a computer terminal or mobile phone, and if the payment does not go well, the customer may have to go to a bank, so it is not possible to assume that alternative payment methods will not eliminate loss of time. (7) Also, as long as cash currency remains, there is a limit to the cost reduction. This is more likely to be brought about by the evolution of FinTech using artificial intelligence (AI) than by going cashless.

Points (8) and (9) have been cited as benefits, considered from an economy-wide perspective. The argument in (8) has been proposed by Rogoff (2017) and many other experts; but empirically, it is unclear to what extent the underground economy and crime would be reduced. Simply put, if there is a separate objective of tax evasion and crime in the underground economy, going cashless will only lead to flight to anonymous payment methods that are alternatives to cash. Public finance economists regularly measure the size of the underground economy, and Japan's underground economy is estimated to be less than 10% of GDP, which is considerably lower than that of other developed countries. The fact that there is little relationship between cash and crime is probably one of the reasons cash can be used with confidence. As for point (9), it has been widely confirmed that citizens of developing countries who had no contact with finance until now have been able to participate in many economic activities by acquiring payment functions through mobile phones. However, this is probably an issue that is not directly related to the cashless society as it happened, because the information and communication industry entered the payment business.

If we assume that cash will continue to exist, there will be additional costs to the existing cash management costs, such as infrastructure development and technology investment for cashless transactions. If we assume that cash will continue to exist, it would be correct to assume that there will be additional costs, such as infrastructure development and technological investment, to existing cash management costs. In this context, if cash management costs are reduced by progress in the shift to cashless transactions, and if there is still a surplus even after investing the extra funds in infrastructure and technology development for cashless transactions, then the shift to cashless transactions will continue. On the other hand, if cash management costs cannot be reduced to such an extent that the cost of additional capital investment becomes a burden, progress toward a cashless society may not be as rapid as it could be.

As we will discuss in Sect. 7.5 of this chapter, if we consider that the shift to a cashless society is a by-product of the evolution of AI and FinTech, particularly in financial institutions, it is difficult and too simplistic to merely compare cash management costs with capital investment costs for a cashless society.

7.4.2 Disadvantages of Going Cashless

When considering the advantages of going cashless, many argued that it would reduce the cost of maintaining cash. The disadvantages of going cashless are, of course, the inconvenience of suppressing the use of cash and the fact that the scale of theft is limited by the physical constraints of cash. With electronic money and virtual currency, theft on a large scale that is unthinkable with cash can, in principle, occur at once.

Some countries, such as Sweden, Denmark, the United Kingdom, and South Korea, have given some retailers the authority to refuse to accept payments in cash in order to promote cashless transactions. One can argue that such measures are necessary to some extent to promote a cashless society, but cash is the so-called last means of payment for those who are alienated from finance. Refusal of cash payment may be acceptable in clubs or schools where the members are fixed, but it is preferable not to allow refusal of cash payment in places where an unspecified number of people may carry out transactions.

To begin with, the government's "Strategy for the Revitalization of Japan, Revised 2014" stated that the government would "work to improve the convenience and efficiency of payments through the widespread use of cashless payments in light of the hosting of the 2020 Olympic and Paralympic Games in Tokyo and other events. In other words, the government's proposal to go cashless included the goal of making it more convenient for the rapidly growing number of anticipated foreign tourists.

In this light, we should not be so preoccupied with promoting a cashless society that we inconvenience not only domestic consumers but also foreign tourists in making payments. I myself have been refused cash payments in Denmark and the UK, but I managed to cope with the situation using a highly versatile credit card. In the trend of internationalization, the payment methods that are easy for foreign tourists to use are those that they use in their home countries (e.g., Alipay, Apple Pay, bank debit cards). In order to make these payment methods usable in Japan, it is necessary to create a mechanism to authenticate the payment methods in the Japanese payment system.

Japanese financial institutions are open to the idea of going cashless in the sense of replacing a portion of domestic cash payments with credit and debit card payments, or replacing cash by issuing privately issued digital currency using blockchain technology, but they are very cautious about allowing compatibility with electronic money and debit cards issued overseas. A delay in addressing this part of the problem could lead to the creation of a Galapagos-island-like cashless society specifically evolved only in Japan, which would indirectly exclude foreign travelers.

The other disadvantage is the security problem. On January 26, 2018, 0.5 billion cryptocurrency XEM (currency unit of NEM, equivalent to 58billion yen at market value) was stolen via on-line within ten minutes or so. At the end of March 2018, the entire amount 0.5 billion XEM was converted into other cryptocurrencies and ultimately into legal tender, and the culprit has yet to be caught. The theft of cryptocurrency has often occurred, but this was the first theft on this scale in history.[1]

A robbery of this scale would not have happened in a cash-transport robbery. In other words, to transport 58 billion yen in cash at one time, a truck with a considerable transportation capacity, a considerable number of people, and a considerable amount of time are required, and it is almost impossible to do so without being noticed by a third party.

Coincheck, which was involved in the incident, was found to have a number of problems with its security management after the fact, and was given a business improvement order by the Financial Service Agency (FSA). The incident prompted a review of the FSA's response to the security management system for crypto-currency exchanges under the amended Funds Settlement Law, and on March 8, 2018, the FSA issued business improvement orders to seven exchanges, including Coincheck.[2]

In contrast, debit cards, credit cards, and e-money are properly managed, and banks and other financial institutions may take the view that their security measures are perfect, but as with crypto-currencies, security problems occur where controls are weak. Specifically, there have been frequent incidents of credit card fraud through breaches of credit card information at the retail level. There is also no end to the number of elderly people who become victims of fraud through the use of counterfeit cards and lax cash-card authentication.

It is also impossible to assume that central banks are safe. In fact, although it is unclear how often crises that threaten the security of central banks occur, it seems that attempts are regularly made to use internal email information obtained through unauthorized access to send malware by impersonation.

On February 4, 2016, after business hours, hackers used malware to infiltrate the Bangladesh Central Bank's systems and, using a hijacked account, sent fake money transfer instructions to the Federal Reserve Bank of New York via SWIFT, successfully transferring funds to bank accounts in the Philippines and other locations. The total amount affected by the fraudulent remittance was $101 million, of which about $81 million (about ¥9.2 billion) has not been recovered. It has been reported that such crimes involving central banks have also occurred in Vietnam, Ecuador, and other countries, and the central banks and private banks of each country are required to share information and strengthen security.

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[1] Initially, the NEM Foundation, the custodians of NEM, made an announcement to the effect that the leaked NEM could be automatically tracked by mosaic and that the perpetrators would not be able to redeem it; but in fact, by going through underground exchanges that could not be mosaicked (such as CoinPayments) In fact, they were exchanged. The NEM Foundation has also quickly abandoned its mosaic tracking system. Although crypto-currencies have been thought to be traceable because their transactions are public, this incident has shown that there is considerable demand for criminally involved crypto-currencies to be purchased in exchange for other crypto-currencies. If they could be obtained at low prices,, it became clear that the system would not work.

[2] The security of the crypto-currency itself and the security of exchanges and exchangers are often discussed in a confused manner, but the security of the crypto-currency itself, which uses public key cryptography, and the security of the Internet environment of exchanges are two different issues. The hackers who stole the private key by breaking in through a lax security system have made it an urgent issue to strengthen the security of exchanges and exchangers.

As we have already seen, more than 90% of household payments are made electronically, and an even higher percentage of businesses rely on electronic payments. The reality is that cash holdings have been whittled down to a minimum, and the trend toward a cashless society is unlikely to stop. As a result, it is only natural that criminals will shift their focus from cash to electronic payments through the manipulation of digital information. Even if the government promotes the shift to cashless transactions, it should take sufficient security measures, recognizing that the risk will be exposed to consumers and retailers, who are the least security-conscious, and that criminals will exploit this risk.

7.5 Policy Issues

Japanese society is facing a variety of structural problems, including a declining birthrate, aging population, depopulation of rural areas, and difficulties in succeeding for individual businesses. At the same time, advances in information technology (IT) have led to the automatic accumulation of big data via the Internet, and AI has come to be used in the economy and society to replace human judgment through machine learning mechanisms such as deep learning. The financial industry is also being forced to change in the midst of this major historical trend, and the major megabanks are responding with a series of plans to close branches and cut staff.

A cashless society will inevitably emerge as part of the economic and social transformation. It is important to develop the infrastructure, including the legal system, and promote a competitive environment in order to achieve this. Moreover, a cashless society will emerge as a by-product of the industrial revolution centered on the broader development of information and communications, and the cashless society itself will not play a leading role, nor is it appropriate to set it as an independent policy goal.

I would like to point out two policy issues. First, an e-government system should be established as soon as possible to provide highly convenient administrative services and efficient administrative operations by digitizing government administrative procedures and settlements for tax payments, social insurance premiums, and pension benefits in an integrated manner. One of the reasons the Nordic countries are using personal identification numbers to make various administrative services online is to cope with their low population density relative to their land area. It is estimated that Japan's population will reach half of its current level (63.5 million people) around 2100, if demographic trends remain unchanged. It is difficult to imagine what will happen socio-economically if the population density is halved, but in Finland and Sweden, if you go out of the cities to the suburbs, you will find endless forests and lakes with hardly a soul in sight. In England and France, the winters are not so severe, so even if the population density is low, the land can be used as pasture or farmland. In Japan, however, there are many mountains, so the flat land is barely used as farmland, but the mountain forests are almost completely abandoned. In any case, it is almost certain that it will become impossible to provide the same level of administrative services as at present as the population continues to decline.

One of the most advanced examples is the digitization of the Estonian government, which has been introduced by Okina et al. (2017, Chap. 16) and Arikivi and Maeda (2016). The Estonian government is trying to determine the extent to which the government can digitize the current situation, and this is possible because Estonia is a small country with a population of 1.3 million. However, compared to the current situation where only about 10% of the population has obtained a My Number card, even though the Japanese government has introduced a My Number card (i.e., National Identification Number Card in Japan), it seems a world away.

For example, it is said that more than 60 billion yen is currently required to hold each House of Representatives election. If this could be converted to online voting using the My Number system that each person has, the cost savings would be substantial. In the first place, if voting could be conducted with a fixed voting period, there would be no need to choose a specific voting date among various schedule adjustments. In many ways, e-government would allow for more agile government operations at less cost and with fewer people, but we must change the current situation, which has not even reached the stage of discussing the possibility.

Second, in connection with the shift to a cashless society, the question of what to do with the cash issued by central banks will also be unavoidable. As can be seen in Fig. 7.1, the ratio of cash balances in circulation to nominal GDP has doubled over the past 20 years. Using the quantity theory of money, a rough estimate is that nominal GDP grew by only 7.6% over the 22 years from 1994 to 2016, while cash grew by 13%. If prices have not changed that much, it means the velocity of cash in circulation has halved. As the shift to cashless transactions progresses, the demand for currency for settlement reasons will decline, and we cannot deny the possibility that it is being held in reserve within households, corporations, and private financial institutions under zero (negative) interest rates. This means that the transmission mechanism of monetary policy is also undergoing a transformation.

The Bank of Japan (BOJ) has been pursuing quantitative and qualitative monetary easing since April 2013, but the reason the policy has not been effective is that there may be a discrepancy between the monetary policy tools chosen and the direction of the policy and the trend toward electronic finance and FinTech, as seen in the shift to cashless banking.

As we have seen in this chapter, more than 90% of total payments are made electronically, and if the cashless system continues to advance further, the demand for cash will decline. At present, no major country has decided to abolish the issuance of currency, but it is a natural progression to consider whether to gradually reduce the supply of cash and to issue the minimum necessary, or to circulate a central bank digital currency (CBDC) that can be used in cyberspace.

While Bitcoin and other crypto-currencies/assets have been pointed out as having problems, there is a growing recognition that they are innovations with potential for a variety of applications.[3]

It is not the purpose of this chapter to discuss the future of money. I will only point out the following. As a researcher who has been thinking about this problem, I can say that it is more difficult than expected to devise a digital currency that can be easily carried around like paper money and yet be useful in cyberspace.

7.6 Conclusion

The choice of means of payment by economic agents should be left to the judgment of economic agents, not something that should be made a policy goal. If a particular technology or service is in its early stages and the government intends to foster it, it may be willing to protect or subsidize it for a certain period of time, but payments are already a mature technology, and cash has existed for more than 2,700 years or so.

There is no need for the government to provide incentives to promote a cashless society. In the first place, the act of payment itself is a means for the purpose of consumption of goods and services, not an end in itself. Cashless transactions are the result of the choice of payment methods. As electronic commerce expands further and retailers voluntarily introduce multi-payment functions, the shift to cashless transactions will naturally occur.

Rather, what is important is the argument that a cashless society will be born as a byproduct of the various IT and AI applications resulting from advances in information technology, as they become a response to structural problems such as the declining birthrate, aging population, and depopulation of rural areas.

As a technical response to structural problems, we should not forget that among the policy issues to be considered are also the issues of how to combine and implement policies (policy mix problem) and in what order (policy sequence problem). The private sector has had the unpleasant experience of becoming "Galapagosized", being left behind by international competition and international standards, while being preoccupied with fighting for a small domestic market share in the name of competition policy. I hope that payment technology will not make the same mistake.

[3] There have been various debates over central banknotes. Black (1970) and Fama (1980) have discussed the economy without money, especially monetary, under a general equilibrium model; Woodford (2000) has discussed monetary policy without money; and central banknotes have been discussed in the literature. Moreover, since Eisler (1933), Goodfriend (2000), Buiter (2005), Rogoff (2014), Agarwal and Kimball (2015) and others have made various proposals for mechanisms that could add negative interest rates to money. The possibility of a digital currency issued by a central bank has also been discussed by Barrdear and Kumhof (2016), Skingsley (2016), Bordo and Levin (2017), BIS (2018), Prasad (2018), and others.

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Chapter 8
The Future of Money or Quest for Good Money

8.1 Introduction

We live in the fourth industrial revolution, based on the Internet and digital technology. Our society is in the process of digital transformation (DX). Naturally the future of money depends on this process.

What is the main feature of the digital society? Looking back at human history after the first industrialization in the eighteenth century in Europe, we see that society began engaging in a lifestyle of mass production and mass consumption. Many products were standardized so that many people enjoyed the same quality of goods and services. These changes improved the standard of living and the quality of life to a large extent in the nineteeth and twentieth centuries. Consequently, the global population exploded after the nineteenth century. At the beginning of the twenty-first century, however, economic and population growth declined gradually in advanced countries. The fourth industrial revolution has emerged as both a consequence of and a compensation for the trend as well.

My diagnosis for the sluggish economy is that our economic statistics or indicators are still based on the twentieth century's modes of production and consumption, while the reality is shifting rapidly to the twenty-first century's lifestyle, i.e., an individualistic pattern of production and consumption. Economists and politicians still talk about Gross Domestic Product (GDP), but many experts recognize, due to digital technology, that we can pay more attention to the living conditions of individuals in detail. If the individual quality of life or the standard of living improves, the slow GDP growth may not matter. At the moment, while we recognize the GDP is no longer a useful indicator of the economy, we have not transformed our social infrastructures to collect individual information automatically and to use or analyze it properly. This is the current situation.

It is quite clear that we need to reach a social consensus on how to collect digital information, how to use it socially, and where to store it. At the moment, each company collects and uses information as they like. The government collects individual information and statistics for administrative and policy-making purposes on

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the basis of the individual ministry or governmental department. Academic institutions such as universities and research institutes also collect information and statistics for their research purposes. It is time to share information and statistics socially, to allow the agents (the government, the company, the individual researcher, etc.) to use them openly and to store them safely. In the fourth industrial revolution, data play a central role, and all infrastructures and analytical tools are focused to facilitate data analysis. The future role of money will find its place in the digital society accordingly.

8.2 Cryptocurrency or Cryptoassets

Bitcoin arrived as a mega surprise to financial market experts. This cryptocurrency does not require any office staff, money issuance agents, or central settlement office. It is conducted almost automatically as written in the protocol in January 2009. Until now (as of January 2022), Bitcoin has been issued mechanically without any serious disturbance. I can imagine that many hackers and experts have tried to intervene and hack the Bitcoin system, but they have failed so far.

From the early days, most economists around me have argued that Bitcoin is a private token without any real asset backing (i.e., private fiat money) and without any representative agent (i.e., no economic entity), and that Bitcoin itself contains only a line of cryptography, nothing else. If people take Bitcoin as a 100% bubble, the Bitcoin market would have collapsed earlier. But in reality, after 13 years on, Bitcoin is still producing new Bitcoin and many people are mining it every minute. Furthermore, a country like El Salvador approves Bitcoin as legal tender. How can we explain this? At least some people believe in the intrinsic value of Bitcoin (e.g., mining costs), no matter how its price fluctuates.[1] Some countries buy Bitcoins for the purpose of hedging against the major currencies, especially against the U.S. dollar. In fact, the group of people who innovate with Bitcoin simply practice issuing cryptocurrency in cyberspace. They do not do any financial trading (borrowing and extending loans) and hedging using Bitcoins, and Bitcoin has no link with the legal tender, so there is no risk of default against the Bitcoin ecosystem itself.

As opposed to an autonomous Bitcoin, some people want to issue so-called stablecoin, which is a collateral-backed cryptocurrency. They say that Bitcoin or Ether is too volatile to be used as a medium of exchange. It sounds odd because not many people hold Bitcoin or Ether for the purpose of its being a medium of exchange in daily shopping. People are holding Bitcoins for the sake of a store of value in the long-run. In addition, those who are interested in stablecoins also do not intend to

[1] As of January 2022, more than 8,000 cryptocurrencies have been issued. Most of them have no record of trading. As the basic protocol of Bitcoin is available and many textbooks on cryptocurrency are published, it is quite easy to issue new cryptocurrency. But it is difficult to add fundamentally new features to the original Bitcoin protocol. The Bitcoin's intrinsic value rests in its decentralized autonomous organization structure. This is indeed a very innovative idea and it attracts many supporters among Internet users and others.

use it as a medium of exchange but as a financial asset. In other words, financial market investors hesitate to invest in Bitcoins because of no collateral backing, but they may be happy with stablecoins because of its collateral backing.

Unlike Bitcoins, stablecoins seem to be designed to attract the financial market participants.[2] The team of stablecoin makers emphasize the stability of its value against the U.S. dollar. Needless to say, the U.S. dollar is fluctuating against other major currencies. Stability is all relative. The other aspect to draw your attention is that the U.S. dollar exchange rate volatility is definitely more stable than that of the Bitcoin and U.S. dollar exchange rate. But the Bitcoin price has gone up more than 60 times in the past 5 years. Which is more attractive for investors?

8.3 Central Bank Digital Currency

There is no doubt that central bankers around the world were jarred by the announcement of Libra (the global digital currency now called Diem) by Facebook (now called Meta). All of sudden, central bankers start discussing central bank digital currency (CBDC) after Facebook's announcement on June 18, 2019. The stated goal behind Libra (Diem) is to create a global currency for the billions of people, both individuals and businesses, without access to traditional financial services and capital. It was the launch of a cryptocurrency with a potentially disruptive effect on the financial industry by a big platformer. Recently, the Diem project has faced setbacks from the regulators (FRB and the U.S. Congress). Meta in fact has withdrawn from this project. This news must reduce the pressure on the central bank community to create CBDC urgently.

The major countries' central banks—namely, Bank of Canada, Bank of England, Bank of Japan, European Central Bank, Federal Reserve, Sveriges Riksbank and Swiss National Bank, and the Bank for International Settlements—started a joint project of studying CBDC in January 2020.

They emphasize its merits in (1) technological efficiency, (2) financial inclusion, (3) prevention of money laundering, tax evasion and criminal activities, (4) safety and robustness of payment system, (5) reduction of cash transaction costs, and (6) improving cross-border payments. The risks would be in (1) suppressing private sector innovation, (2) centralization, and (3) bank disintermediation.

At the moment, the major central banks conduct research and experiments for CBDC feasibilities. They exchange views at BIS, IMF, and the like. They also monitor the private digital currencies carefully as they did for Libra (Diem). They have not reached any decisions as to when they will introduce CBDC. As we saw in Chap. 5, the private sector has already introduced electronic money and they are used intensively

[2] I personally feel that stablecoin is like the Monkees in the 1960s, the U.S. counterpart of the Beatles from Britain. The U.S. show business industry created the Monkees and achieved some success. But in terms of impact on the music world, there could be no comparison: In the cryptocurrency world, Bitcoin is definitely the Beatles.

in Japan. Unless substantial innovations in the digital currency are found, the Bank of Japan may not have a strong motivation to introduce CBDC soon.

However, it is important to design the digital currency with the private sector and the other central banks across the world, so that new CBDC framework facilitates the future coordination, for example, in cross-border payments. Furthermore, the Bank of Japan should take the initiative in building an open access public database in the digital era whether it is used for CBDC or not.

8.4 Back to the Basics

8.4.1 One-Yen Coins

When a country issues new money, what does an individual care about? First of all, the design of notes and coins secondly, security against counterfeits; thirdly, the amount/number of issues and, fourthly, when to issue.

I would like to introduce a story of the one-yen coin in 1955. Ten years after the end of the Second World War, Japan was recovering from the damages and losses that occurred during the war. The postwar hyperinflation had settled down and new construction of infrastructure building across the nation had just begun from the early 1950s. The government of Japan decided to issue new one-yen coins and called for a design competition publicly for the first time. Out of 2,581 applications, the surface (head) design of young tree by Masami Nakamura (Kyoto) and the back (tail) design of 1 by Toshio Takashima (Osaka) were selected. The Ministry of Finance commented on the selected design of an anonymous young tree as the symbol of new growth in Japan and as anonymity applying for everyone in society. This new issue of one-yen coin was a very symbolic event; this is the only coin design selected through an open competition. We felt that everyone in society had stood up from the ashes and decided to walk along our road together. The one-yen coin story does not stop here, however.

Not many people recognize that a one-yen coin, the minimum denomination of Japanese money, weight 1 g and its radius is 1 cm. It is literally the basic unit of measurement on earth. Let me explain how we reach the *metre* and *gram* standard.

The history of the meter starts with the scientific revolution initiated by Nicolaus Copernicus. Scientists looked for measures that were universal and based on natural phenomena. With the French Revolution in 1789, a new unit of length, the meter, was introduced on October 7, 1790. It was defined as one ten-millionth of the shortest distance from the North Pole to the equator passing through Paris. This measurement of one meter is based on the size/distance of the earth which all human beings inhabit. It is also based on the decimal system (10 mm = 1 cm, 100 cm = 1 m, 1,000 m = 1 km, etc.).

The weight measurement of *gram* is also based on the meter. It was defined in 1795, such that the absolute weight of a volume of pure water equal to the cube of the hundredth part of a meter (1 cm^3), and at the temperature of 4 °C at which water reaches its maximum density. Of course, the measurement of a gram is also based on the decimal system, such that 1,000 g = 1 kg, 1,000 kg = 1 ton.

Water is essential material for human beings. Without water, no one can survive on earth. The decision made by the French National Convention to use pure water as the base of weight standard was accepted globally. There is nothing more natural than pure water. Many countries adopted the meter–gram measurement standard in the nineteenth century. Japan did so in 1885. As far as I know, accuracy in measurement of length and weight has improved as scientific technology advances,[3] but the fundamental idea of meter and gram based on the size of the earth remains. A one-yen coin, very small in value and size, reflects the basic unit of meter–gram standard, sharing the same measurement across the globe. Needless to say, the Japanese yen did not intend to be a global currency but was simply a local currency with a modest hope of being accepted and used by earthlings, as Japan was scheduled to join the United Nations in December 1956. I hope the Bank of Japan's CBDC, if issued, will inherit the spirit of the one-yen coin.

8.4.2 Communication and Money

Marshall McLuhan (Media) says that money is a communication medium that conveys the idea of value.

In days past, we visited local retail shops for daily consumption. At the shop, the buyer and the seller would exchange information and make sure the quality of the goods and their price were decent. McMillan (2002, pp. 5–6) argues:

> What characterizes a market transaction? Decision-making autonomy is key. Participation in the exchange is voluntary; both buyer and seller are able to veto any deal. They are separate entities. Controlling their own resources, the participants in a market, in deciding how those resources are to be used, are not obliged to follow others' order. They are free to make decisions—to buy, to sell, to exert effort, to invest—that reflect their own preferences. Their choices are not completely free, though: they are constrained by the extent of their resources and by the rules of the marketplace.

In order to make our decision autonomous, we need sufficient communication between buyer and seller, and for both sides to fully understand what the buyer wants and what the seller has, then decide to buy or not to buy. The role of the marketplace or the bazaar is to reduce and, desirably, eliminate information asymmetry between buyer and seller by means of repeated trading and reputation among the market participants.

In the digital era, can we conduct the same density of face-to-face communications at the bazaar? Do we know the companies or the products listed in shopping pages of

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[3] Nowadays the *meter* is the International System of Units (SI) of length. It is defined as the length of the path travelled by light in a vacuum during a time interval of 1/299792458 of a second. In short, now the unit of length is measured in terms of a time (more precisely the speed of light) because time can be measured more accurately than length.

Amazon? I think information asymmetry has been widened in recent years, and that creates many mismatches not only in the goods market, but also the labor market, even in the marriage market.

From the goods market, we hear a lot of clothes and foods are discarded and burned. From the labor market, many workers quit job frequently, never obtain high skills, and remain peripheral positions in society. From the marriage market, the divorce rate has risen, whatever the reasons may be. In Japan, more peculiar things are happening. That is, 25.7% of men and 16.4% of women stayed single until age 50 in 2021. About one-fourth of men have no chance to get married, so no wonder the population declines.

I do not think all these mismatches are due to lack of communication and mutual understanding, but maybe due to money. Indeed, money is involved in all market transactions. Messages in money convey some implications or interpretations from the other side, as McLuhan said.

It may be a time to reinvent the bazaar, as John McMillan proposed. One way to reinvent market communication is to build the open access database. McMillan (2002, p. 46) said,

> Buyers are empowered by anything that makes it easier for them to acquire information. Any market innovation that lowers search costs, such as the advent of electronic commerce, makes markets more efficient. People waste less time and money on search. Better matches of buyer and seller are formed, and pricing becomes more competitive, to the buyer's advantage.

In the digital era, innovation with respect to the digital currency has something to do with information and the database. In a broad sense, it is to do with communication. Think about the fact that we pay with digital currency through the Internet as we send e-mail from our smartphone, and that we usually install its wallet on our phone. Now the digital currency becomes literally a part of our communication tool.

8.4.3 Democracy and the Internet

Alexis de Tocqueville (1835) describes the principle of the sovereignty of the people of America as

> [T]here [in the United States] society governs itself for itself. All power centers in its bosom, and scarcely an individual is to be met with who would venture to conceive or, still less, to express the idea of seeking it elsewhere. The nation participates in the making of the laws by the choice of its legislators, and in the execution of them by the choice of the agents of the executive government; it may almost be said to govern itself, so feeble and so restricted is the share left to the administration, so little do the authorities forget their popular origin and the power from which they emanate. The people reign in the American political world as the Deity does in the universe, they are the cause and the aim of all things; everything comes from them, and everything is absorbed in them. (Tocqueville, 1835. *Democracy in America*, Vol.1, Chap, IV, "The Principle of the Sovereignty of the People of America)

This is how democracy in modern times started. The founding fathers built an autonomous democratic society in 1776. About 250 years later, U.S. society is divided badly between two groups of people. If this is a result of the Internet or social networking services (SNS), how we can fix it? Or if all useful digital tools tear apart an autonomous democratic society, should we control them? This problem emerges from a mixture of deterioration of democracy, social division by digital technology, and differences in socioeconomic conditions among regions and across occupations.

Tirole (2021) challenges the issues related to social division by digital technology. He tries to compare the bright side of data use in a more civilized society and the dark side of digital dystopia. He concludes it is important to understand the channels through which a dystopic society might come about, so as to better design legal and constitutional safeguards.

In this book, I take the position that our society is being transformed by digital technology, that we need to set up some basic frameworks for the digital currency, and that the open access database on the individual and economic entity must be constructed for the purposes of policy making and business uses (the digital currency is one of them).

As Tirole suggests, the autocratic regime might use the database for the sake of controlling or oppressing people. We must pay full attention to such a possibility. On top of that, the open access database should have a blockchain-like nature so that even the government cannot revise the data.

All democratic societies face a similar problem of political instability of the ruling regime, probably due to fluctuation of political voters. Some politicians, media, and intellectuals might express positive views about autocratic regimes and its efficient policy operations. I would recommend them reading Hayek (1944).

8.5 What is the Future of Money?

We use the Internet nearly all the time. It is natural to design a new digital currency that can be used online without involving an unnecessary third party. Recall that we can buy things through Amazon and pay by credit card, electronic money, or net banking; and we can sell goods on market platformers and receive sales payments (revenues) through various methods. Transaction fees or handling costs with a third party are a part of security in payments. Of course, we can reduce transaction fees or monitoring costs via Internet technology or artificial intelligence with P2P transactions. However, not all transactions are P2P, the roles of financial intermediaries and transaction settlement remain. We would rather think of other directions of its use for the future of money.

8.5.1 Expansion of the Boundary of Numbers and Matching

As we saw in Chaps. 2 and 3, cash is based on natural number denominations such as 1 dollar, 5 dollars, 10 dollars, 20 dollars, 50 dollars, and 100 dollars. On the accounting (book) base, we can consider a negative integer, a rational number (fraction; n/m). In economic theory, the maximum boundary of numbers is the real number, including irrational numbers such as π, e, and $\sqrt{2}$. Pricing and payment settlement normally use natural numbers.

Digital money can use a much wider range of numbers such as the complex numbers, quaternion (4-elements complex numbers), or octonion (8-element complex numbers). All these mathematical concepts of numbers can be handled by computers, as in a digital money wallet.[4]

As an aside, a bit is a binary digit, the smallest increment of data on a computer. A bit can hold only one of two values: 0 or 1, corresponding to the electrical values of "off" or "on", respectively. As bits are so small, you rarely work with information one bit at a time. Bits are usually assembled into a group of eight to form a byte (i.e., 8 bits = 1 byte; $2^8 = 256$ patterns of information). A byte contains enough information to store a single ASCII character, like "h". A kilobyte (KB) is 1,024 bytes ($=2^{10}$), not one thousand bytes as might be expected, because computers use binary (base two) math, instead of a decimal (base ten) system.[5]

We have not explored enough as to what we can do with digital information technology. Many economic and social decisions are made on the tradition of the analog world. We often discuss the digital transformation (DX) which is supposed to change our lifestyle fundamentally. It seems that only a small fraction of companies or organizations go through digital transformation, whereas a vast majority of companies and organizations remain unchanged and do not know which way to go.

How can digital currency be used in new era? Take an example from food consumption. With advances in biological knowledge, we are quite familiar with allergic reactions to food ingredients. We are also sensitive to contents of foods in terms of health (e.g., in diabetes) and increased awareness of obesity. Sometimes, allergic reactions cause death. Those who are sensitive to food contents pay close attention to dangerous ingredients. Nevertheless, food poisoning and allergic reactions occur all the time. This is because food producers may not fully explain the contents and ingredients of their products to their customers and may not list all the ingredients in the packages of their products. School meals may cause allergic reactions and food poisoning among school children because of lack of attention of allergy-causing materials and food conditions by school cooks. All these problems

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[4] Mathematics using these complex numbers goes beyond the scope of this book.

[5] Quantum computing will handle the basic quantum information unit as a *quantum bit* (qubit), which can take any numberss between 0 and 1—say 0.6 or 0.1— whereas the classic binary bit takes only 0 or 1. There is an idea of quantum money that is a proposal for creating banknotes by using quantum physics. This idea is still premature because the quantum bank notes require storing the quantum states in a quantum memory. Quantum memories can currently store quantum states only for a very short time.

can be substantially reduced by means of digital information requirements on foods and other health-related items.

An example is to make an information tag with a QR code in which price, ingredients, history of cooking, origins of food materials, and nutritional contents, among others, are listed. Consumers use a smartphone application (in the digital currency wallet) to read the QR code, to analyze food information, and to decide to buy or not to buy. In so doing, consumers are better able to avoid buying unsuitable foods.

This type of automatic selection of consumption goods is not restricted to foods but other items such as alcohol, tobacco, and gambling. This smart digital currency wallet can also examine individual items or components in insurance contracts, as with life (non-life), car, or property and then selects the insurance contract that is exactly what the buyer wants.

The future of money in this context requires a wider set of information including the price, other characteristics, and production information. To put it differently, in the digital era, we need to build a large database for each individual. It could be a actual database in the cloud or a virtual database in which all information is located separately and is assembled as required. Digital money uses a part of this individual database for purchasing decisions and payment purposes.

Individual consumers have to provide private information about bank accounts, health conditions, allergy-sensitive items, individual preferences. The smart digital currency wallet has access to the individual information. With this arrangement, the smart wallet can select consumption goods by matching two-sided information. In a sense, the digital currency communicates with goods and services and makes machine-aided personal decisions.

This idea originally comes from Hahn (1971). He defines named goods as well as anonymous goods that distinguish a given physical good at a particular time and place owned by an agent from the same good when it is being bought by another agent. This distinction allows Hahn to discuss households facing a sequence of budget constraints and the possibility of there being no unique set of discount rates applicable to all households. Sen (1976) employs the term "named good" in a different context. He defines commodity j going to person i will be called a "named good", ij, the amount of which is denoted by x_{ij}. Sen (1976) proposes the measurement of real national income. The meaning of the same commodity differs from person to person. This concept later led to Sen's capability approach (Sen, 1987). Our discussion of consumer goods with price and characteristic information matched with an individual digital currency wallet is a natural extension of Hahn and Sen's concept of named goods in the digital economy.

8.5.2 Expansion of Time Dimension

Another extension would add the time dimension to digital currency. In fact, the Bank of Japan 10,000-yen notes have an eight- or nine-digit serial number that indicates where and when they are issued. Coins explicitly indicate the issue-year on their surface. If a cash dispenser is equipped with a sophisticated serial number scanner, we can handle individual cash differently. Early days in the beginning of twentieth century, the idea to put a time-stamp on the bank notes was discussed by Gesell (1918). At that time, a sophisticated-enough cash dispenser was not available, so that Gesell said that the owner of bank notes periodically would have to buy and affix stamps to the backs of bank notes to maintain their value. This would be equivalent to imposing a negative interest rate on cash or to levying a tax on cash holdings. This idea attracted much attentiona from eminent economists like Irving Fisher and John Maynard Keynes. They believed at first that this idea could be a tool for fighting deflation. In the end, they rejected Gesell's idea as impractical.[6]

Digital currency now can easily accommodate a negative interest rate as long as the database accepts the time-dimensional information. This is directly related to monetary policy. Needless to say, the effectiveness of monetary policy depends on how cash remains in use.

In addition to the monetary policy issue, a company accountant can access information about production flows such that how the final goods are produced with intermediary goods and raw materials, how much value is added in each production stage, and how much value-added taxes are paid in the upstream (invoice record), so that the company can decide the price of a product. This makes the production process transparent.

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[6] Rogoff (2016) discusses the possibility and merit of abolishing paper money. In so doing, he elaborates the way to impose a negative interest rate on cash. He mainly discusses how to handle individual notes with magnetic strips or radio-frequency identification chips to manage

interest rates or stamp duty,, but he did not discuss the digital currency wallet as we have done here.

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