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Technology Diffusion within Central Banking: The Case of Real-Time Gross Settlement

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Abstract

We examine the diffusion of real-time gross settlement (RTGS) technology across all 174 central banks. RTGS reduces settlement risk and facilitates financial innovation in the settlement of foreign exchange trades. In 1985, only three central banks had implemented RTGS systems, and by year-end 2005, that number had increased to ninety. We find that the RTGS diffusion process is consistent with the standard S-curve prediction. Real GDP per capita, the relative price of capital, and trade patterns explain a significant part of the cross-country variation in RTGS adoption. These determinants are remarkably similar to those that seem to drive the cross-country adoption patterns of other technologies.

Key words: central bank, technology, diffusion, S-curve, payment systems, RTGS

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Introduction

Modern growth theory suggest that financial sector development affects long-run growth. One of the basic functions of the financial sector is to provide efficient mechanisms to make and receive payments. By reducing transaction costs the payment system facilitates trade and allow greater specialization by agents in the economy. Over the past few decades there has been a rapid rate of technological innovation in the financial sector. Nowhere is that more apparent than in the electronification of means of payment.

In most countries, the payment system is provided by commercial banks in a symbiotic partnership with the central bank. Central banks tend to provide the medium to settle small payments (i.e. cash) and to support an interbank system that settles large value and time-critical payments. A small but growing literature is analyzing how and why commercial banks adopt new technologies e.g. Hannan and McDowell (1984), Gowrisankaran and Stavins (2004) and Akhavien et al. (2005). However, no studies have to our knowledge focused on central bank adoption of new technologies. This is surprising given the key role, the central bank plays in the financial sector. Moreover, the adoption decision by a central bank is potentially interesting in its own right as it might be different than the profit considerations driving the private sector.

Rogers (1995) defines diffusion as a process by which some type of innovation is communicated through certain channels over time and space among the members of a social system. An innovation is any kind of idea, object or practice that members of the social system perceive as new. Here, we describe the diffusion of a new technology within central banking and seek to identify the determinants of adoption by using a new data set on the implementation of real time gross settlement (RTGS) systems across the international community of central banks.

Historically, interbank payments have been settled via end-of-day netting systems. In a netting system, payments are accumulated over the course of the business day. At the end of the day, all positions are tallied up, and money is exchanged on a net basis between the participants. The volume of interbank payments has increased dramatically over the last 30 years, mainly due to the before mentioned rapid financial innovation and the integration and globalization of financial markets. As the volume and value of transactions increased, central banks became worried about settlement risks inherent in netting systems. In particular, central banks were concerned about the potential for contagion (or even a systemic event) due to the unwind of the net positions that would result if a participant failed to meet its obligations vis-à-vis the system when due. Consequently, over the last couple of decades, many countries have chosen to modify the settlement procedure employed by their interbank payment system with a view to reduce settlement risks and the potential for a systemic crisis. Most central banks opted for the implementation of a real time gross settlement (RTGS) system. An RTGS system eliminates the settlement risk from one or more participants failing to make due, as payments are settled irrevocably, with finality, on a individual gross basis and in real time.

By 1985 three central banks had implemented an RTGS system. A decade later, that number had increased to 16, but RTGS was still utilized predominately by industrialized countries. In recent years, however, both transitional and developing countries have begun investing heavily in improving their financial systems and now RTGS is a common choice for the interbank payment system. At the end of 2005, the use of RTGS systems had diffused to 90 central banks.

We analyze our data in two different ways. First, we consider the pattern of RTGS adoption over time and space. We estimate an S-shaped adoption curve, similar to those estimated by Griliches (1957), and find that, in all likelihood, it will take at least another 15 years before RTGS is fully adopted. Second, we consider the main determinants of RTGS adoption using a discrete time duration model, based on a logit hazard rate. We find that the probability that a country adopts RTGS in a given year increases significantly in the level of real GDP per capita. Moreover, countries with a lower relative price of capital and countries whose major trading partners adopted RTGS are also more likely adopters. This suggests that, beyond market forces reflected by real GDP and capital costs, spillovers seem to play a significant role in the adoption of this financial innovation. These spillovers seem to disseminate mainly through trade relationships.

The structure of the rest of this paper is as follows. In the next section, we describe the role of the interbank payment systems as well as the features of netting and real time gross settlement using the U.S. large value payment system as an example. In Section 2 we introduce our data on the adoption of RTGS and map out the diffusion across the world. In Section 3 we study the S-shaped nature of the world RTGS diffusion curve. Based on the theoretical and empirical literature on technology adoption, we review the potential determinants of RTGS adoption in Section 4 and we briefly discuss our econometric methodology in Section 5. In Section 6 we present our empirical results. We conclude with Section 7. A more detailed description of our data and econometric methodology can be found in Appendices A and B, respectively.

1 Interbank Payment Systems and Real Time Gross Settlement

At the apex of the financial system are a number of critical financial markets that provide the means for agents to allocate capital and manage their risk exposures. Instrumental to the smooth functioning of these markets are a set of financial infrastructures that facilitate clearing and settlement.[1] Many of those infrastructures use the interbank payment system to affect final settlement. In addition, most central banks use the interbank payment system to implement monetary policy, and it serves as the platform for the interbank money market. An efficient and resilient interbank payment system reduces transaction costs for agents in the economy and is a precondition for successful monetary policy and financial stability.

In the U.S., there are two principal systems that settle interbank payments: The Federal Reserve's Fedwire Funds Transfer System® (Fedwire) and the Clearing House Inter-Bank Payments System (CHIPS) – a private sector enterprise. Commercial banks use Fedwire and CHIPS to handle large-value or time-critical payments, such as payments for the purchase, sale, and financing of securities transactions, foreign exchange transactions, settlement of interbank purchases and sales of federal funds, the disbursement or repayment of loans, and the settlement of real estate transactions and other large value purchases on behalf of customers.[2] Through Fedwire, participants initiate funds transfers that are immediate, final and irrevocable when processed. Like other sys-

[1] Clearing is the process of transmitting and confirming payment orders or security transfers arsing from market trades, as well as establishing, possibly by way of netting, final positions for settlement. Settlement is the act that discharges the obligations between two of more parties arising from the market trades. Settlement is final when it is irrevoacble and unconditional. Ultimate settlement is sometimes used to denote final settlement in central bank money.

[2] Several payment and securities settlement systems (including CHIPS) use Fedwire to square final positions over the course of the business day.

tems with these key features, Fedwire is an RTGS system. In fact, Fedwire was the world's first RTGS system. Its origins go back to 1918 when the Federal Reserve inaugurated a network of wire communications among the individual Reserve Banks. The new system of wire-initiated book entries allowed funds to be transferred on behalf of the member banks and significantly reduced the need for physical shipment of gold and currency. In the early 1970s, the Fedwire system migrated to a fully computerized platform, and settlement in "real time" was achieved. During the first year of operation, the Federal Reserve Bank of New York processed around 100 wires per day; 10 years later, they were processing about 600 per day. Today, more than 7,500 participants originate an average of over 520,000 transfers per day. The value of transfers originated has seen tremendous growth The annual turnover increased from around $100 trillion in 1985 to over $518 trillion in 2005, equivalent to an annual growth rate of over 9% (see Figure 1).

The New York Clearing House Association organized CHIPS in 1970 for eight of its members to settle the dollar side of foreign exchange transactions and other large value payments. Participation in CHIPS expanded gradually in the 1970s and 1980s to include other commercial banks, branches of foreign banks and other financial institutions. CHIPS began as a deferred net settlement (DNS) system. In a DNS system payment orders are accumulated over a prespecified time period (typically one day), and settlement occurs on a net basis at some point thereafter. Until 1981, final settlement occurred on the morning of the next business day through the transfer of balances across the books of the Federal Reserve. A sharp increase in settlement volumes raised concerns that next-day settlement unduly exposed participants to various overnight and over-weekend risks. In response, CHIPS began providing same-day settlement through Fedwire in August 1981.

Netting substantially reduces the amount of money needed to settle a given set of obligations. As a rough rule of thumb, $100 in gross payments can be settled by an end-of-day net transfer of $1. A major drawback of (unprotected) netting systems, however, is the risk that a party will default on its payment obligations. If even one participant fails to meet its net obligation when due, all processed payment orders involving that participant may be unwound, and as a result, other participants may fail to make full on their net obligations.[3] Such an event could conceivably

[3]It would be particularly troublesome if funds are credited to customers' accounts by banks expecting final settlement at a later time. This could translate into a credit exposure for those banks that have a limited ability to

set off a cascade of settlement failures that could disrupt the smooth function of the financial system.[4] According to Humphrey's (1986) simulation study of two randomly selected business days in January 1983, the failure of a of major CHIPS participant, given the rules at the time, might have caused dozens of large banks to fail, which could have triggered a system-wide crisis.[5] Accordingly, in response to the wishes of both participants and regulators, CHIPS moved in 2001 to a new settlement system that provides intraday finality.[6] The current version of CHIPS is referred to as a hybrid system, as it combines features of DNS and RTGS.[7] Currently, CHIPS has 46 participants (down from 142 in 1985) representing 19 different countries. In 1985, CHIPS settled $78 trillion, which increased to $362 trillion in 1997. As illustrated in Figure 1, settlements over CHIPS were larger than those over Fedwire from 1988 to 1998. Settlements over CHIPS dipped in the late 1990s, however, and amounted to $350 trillion in 2005. Still, the annual growth rate from 1985 to 2005 was almost 8%. Together payments equivalent to U.S. GDP are originated over Fedwire and CHIPS every 3 and half business days on average.

2 Diffusion of Real Time Gross Settlement

The U.S. experience with interbank payment systems is different from most countries, in the sense that there have been two systems operating for the last 35 years and that RTGS was implemented before DNS. In the rest of the world, there is typically only one large value interbank payment system, and, prior to the 1980s, that system settled payments using deferred net settlement. As interbank payment systems around the world saw similar growth in the value of payments to that of the U.S., settlement risk issues emerged on the forefront of the payments policy agenda of central banks around the world. As settlement risk is virtually eliminated in a RTGS system, many central banks began to consider this option.[8]

reclaim such funds.

[4] See Selgin (2004) for a critique of this line of reasoning.

[5] Similar simulation studies of interbank netting schemes in other countries have not found risks of the same magnitude. See, for example, Angelini et al. (1996) and Bech et al. (2002).

[6] For a description of the current CHIPS system, see www.chips.org

[7] For a discussion of hybrid systems and new developments in large-value payment systems, see McAndrews and Trundle (2001) and BIS (2005)

[8] RTGS can also help reduce settlement risk by facilitating payment versus payment or delivery versus payment in settlement of foreign exchange and securities transactions. However, the elimination of risk comes at the cost of an

In the 1980s a number of Western European countries began implementing RTGS systems. Denmark started the trend in 1981, and the Netherlands and Sweden followed suit in 1985 and 1986, respectively. By 1988, RTGS systems operated in five of the six major currencies (Pound Sterling excluded), as SIC was implemented in Switzerland (1987), EIL-ZV in Germany (1987) and BoJ-NET in Japan (1988). BoJ-NET provided both DNS and RTGS but RTGS was seldom use by banks due to the liquidity costs. In 2001 the Bank of Japan reconfigured BoJ-NET and abolished DNS. Just prior to the change, only about 3% of the Japan's wholesale payments measured in terms of value were settled via RTGS (Selgin (2004)). The last country to implement an RTGS system in the 1980s was Italy in 1989.

In the late 1980s, the central banks of the Group of Ten (G10)[9] countries published the Angell and Lamfalussy reports, which study different aspects of interbank netting schemes. The latter report includes a set of minimum standards for the operation of bilateral and multilateral netting schemes and sets out the G10 central banks' agreed approach for the joint oversight of such systems. In 1990, a permanent committee on payment and settlement systems (CPSS) was created by the governors of the G10 central banks.[10] The CPSS has focused on distributing information on payment system design and has been instrumental in defining the norms and best practises for the central bank community in the area of payments.[11]

During the early 1990s, RTGS adoption continued at a rate of roughly one country per year with Finland in 1991, Czechoslovakia and Turkey in 1992, Poland in 1993 and South Korea in 1994. In 1992, the Treaty of Maastricht created the foundation for the Economic and Monetary Union (EMU). A year later, the central banks within the European Union (EU) agreed that each member state should have an RTGS system. Furthermore, in 1995 the central banks decided to interlink

increased need for intraday liquidity to smooth the non-synchronized payment flows. Intially, central banks provided intraday credit for free to commercial banks. However, this policy is no longer considered a viable option by central banks, as it exposes them (and ultimately the tax payers), as guarantor of the finality of payments, to credit risk.

[9] G10: Belgium, Netherlands, Canada, Sweden, France, Switzerland, Germany, United Kingdom, Italy, United States and Japan.

[10] In 1997 the Hong Kong Monetary Authority and the Monetary Authority of Singapore joined the CPSS.

[11] For example, in 1997, the CPSS published a report on real time gross settlement that laid out general features as well as specifics of the systems in operation in the G10 countries. In 2002, the CPSS published a set of core principles for systemically important payment systems. Moreover, the CPSS recommendations are part of the toolkit of the Financial Sector Assessment Program (FSAP), jointly established by the International Monetary Fund (IMF) and the World Bank in 1999. The FSAP specifically looks at countries' financial sectors, assessing strengths and vulnerabilities in order to reduce the potential for financial crisis.

the national RTGS systems through the Trans-European Automated Real-time Gross settlement Express Transfer (TARGET) system in order to facilitate the ECB's single monetary policy and to promote sound and efficient payment mechanisms in euro.[12]

These decisions led to a flurry of new systems and upgrades to existing ones. TARGET went live on January 4, 1999, and even EU countries that did not join the EMU at the outset were allowed to participate in the system. Denmark, Sweden and the United Kingdom implemented separate Euro-RTGS systems alongside their national RTGS systems for their domestic currencies. Greece eventually joined the Euro on January 1, 2001, and its new RTGS system, Hermes, went live at the same time. The Eurosystem is currently developing a new RTGS system, TARGET2, which will dispose of the national RTGS systems and run on a single technical platform. All Euro-system central banks will participate in TARGET2. Of the "out countries," only Denmark has confirmed its participation, while Sweden and the United Kingdom will not connect to TARGET2. Some new member states' central banks will only participate when they adopt the euro. TARGET2 is planned to go live at the end of 2007 with the changeover completed by mid 2008.

As the European Central Bank (ECB) made RTGS a prerequisite for membership to the EMU, the prospective members in rest of Europe began to implement RTGS, as well. RTGS was implemented in Slovenia in 1998, Hungary in 1999; Latvia in 2000; Bulgaria, Estonia and Malta in 2002; Lithuania in 2004 and Romania in 2005.

As a result of the "velvet divorce" of Czechoslovakia into the Czech Republic and Slovakia in 1993, a copy of the RTGS system operated by the former federal central bank, State Bank of Czechoslovakia, was installed in Slovakia. That system was owned and operated by a private agency, however, so only at the end of the day were the final positions reported to the Slovak central bank, which then settled them on its general ledger. Significantly, payments were not considered to be final and irrevocable until that time. In 2003, the Slovak central bank implemented a new RTGS system to correct this problem. The new Czech National Bank continued to operate the original RTGS system, albeit with payments denominated in its new currency, the Czech Koruna.

[12] The ECB also operates its own RTGS system for its account holders;: the ECB payment mechanism (EPM). EPM is connected to TARGET and is used for settlement of euro positions arising from the EBA Clearing Company (EURO 1) and CLS, the continuous linked settlement system for foreign exchange transactions.

The continent-wide adoption also encouraged RTGS implementation in countries outside the sphere of the European Union and accession countries, as well. Norway implemented RTGS in 1997; Belarus in 1998; Iceland in 2000; and Azerbaijan, Georgia and Ukraine in 2005. As hostilities ended in the Balkans in the late 1990s, governments began to rebuild their respective economies. They considered the establishment of a sound and efficient financial systems a priority. RTGS systems were (with support from the EU and the World Bank) implemented in Croatia (1999), Bosnia and Herzegovina (2001), Macedonia (2001), Serbia (2003), Albania (2004) and Montenegro (2005). With ongoing projects in Russia, Cyprus and Moldova, the diffusion of RTGS in Europe is nearly complete.

Outside Europe the rate of adoption of RTGS since the mid-1990s has been equally impressive. Australia and New Zealand implemented RTGS in 1998 and remain the only countries in Oceania that have gone live with RTGS. In Asia, the rate of RTGS implementation has been fairly steady; on average, about one Asian country has adopted RTGS per year. Other than the early adopters - Japan and Korea - the following countries have implemented RTGS: Thailand in 1995; Hong Kong and Kazakhstan in 1996; Singapore in 1998; Malaysia in 1999; Indonesia in 2000; Taiwan, China and the Philippines in 2002; and Sri Lanka and India in 2003.

Saudi Arabia was the first country in the Middle East to implement RTGS in 1997. Five additional Middle Eastern countries have since adopted RTGS, as well: Qatar in 2000, United Arab Emirates in 2001, Jordan in 2002, Kuwait in 2004 and Oman in 2005. Israel expects its new system to be operational in the first quarter of 2007, and the State Bank of Pakistan is currently in the process of introducing an RTGS system.

In Africa the South African Reserve Bank (SARB) spearheaded adoption in 1998. Through the South African Development Community (SADC),[13] the SARB has participated in developing and strengthening the financial infrastructure in the rest of southern Africa. Among the goals for the SADC is the implementation of RTGS systems. RTGS has been implemented so far in the following SADC member states: Mauritius in 2000; Namibia, Malawi and Zimbabwe in 2002; Botswana in 2003 and Tanzania and Zambia in 2004. The Central Bank of West African States

[13] The member states of the SADC are: Angola, Botswana, Democratic Republic of Congo, Lesotho, Malawi, Mauritius, Mozambique, Namibia, Swaziland, Seychelles, South Africa, Tanzania, Zambia and Zimbabwe.

(BCEAO) launched an RTGS system in 2004 for the members of the West African Economic and Monetary Union (WAEMU)[14].

The Bank of Central African States (BEAC), which is the common central bank for the Central Africa Economic and Monetary Community (CEMAC)[15]. The BEAC shares the Franc CFA as currency with the BCEAO. In addition to these regional efforts, four countries have implemented RTGS systems: Ghana (2002) and Uganda, Kenya and Nigeria (2005). Moreover, the central banks of Algeria, Egypt and Libya have all started RTGS projects. Africa has seen tremendous growth in the adoption of RTGS in the last five years. It is likely that this growth will continue in the near future, as many of the projects in Africa have received World Bank support.

In the Western Hemisphere, Canada is an interesting case. It is the only G-10 country that has decided not to implement an RTGS system. Instead, Canada opted for a system that employs multilateral netting by novation. The Canadian Large Value Transfer System (LVTS) is considered equivalent to RTGS in terms of finality, as the Bank of Canada provides an explicit guarantee of settlement. Mexico began a substantial modernization of its payments settlement systems in 1994. At that time, the Bank of Mexico operated both an electronic interbank settlement system and a manual check clearinghouse. The principal objective of the reforms was to replace large-value checks with electronic transfers through the Bank's existing RTGS system (SIAC). This was accomplished in stages and culminated in the launch of a new RTGS system, SPEI, in 2005.

In South America, Uruguay was the first country to adopt RTGS in 1995. The trend of implementation has since been about one country every two years. Argentina's payment system was substantially reformed in 1997, when the central bank established a new framework for private clearinghouses to modernize the traditional paper-driven systems. At the same time the Argentine central bank also implemented an RTGS system. Colombia followed in 1998, Peru in 2000, Brazil in 2002, and Bolivia and Chile in 2004. In other words, seven of thirteen countries have adopted RTGS in South America.

RTGS implementation in Central America and the Caribbean has only started recently. The Netherlands Antilles and Cuba began using RTGS in 2001 and 2002, respectively. The following

[14] WAEMU members are: Benin, Burkina, Côte d'Ivoire, Guinea Bissau, Mali, Niger, Senegal and Togo.

[15] CEMAC members are: Cameroon, Central African Republic, Congo, Gabon, Equatorial Guinea and Chad.

countries have also implemented RTGS: Barbados and Costa Rica in 2002, Trinidad and Tobago in 2004 and Guatemala in 2005. The Inter-American Development Bank is assisting the efforts to implement RTGS systems in the region.

As illustrated in Figure 4, the world RTGS adoption rate was about one central bank per year in the latter part of the 1980s and in the beginning of the 1990s. In mid-1990s, however, the adoption rate started to pick up with three central banks in 1995 and five central banks in 1996. The annual adoption rate has not dipped below five new central banks since, and it peaked in 2002, when a total of 15 central banks implemented new RTGS systems. By the end of 2005, 90 out of the 174 central banks in the world had adopted an RTGS system for their interbank payments, up from only three countries in 1985 (Figure 2).

3 S-curve and Adopter Categories

An important regularity in empirical studies of technology diffusion is that the rate of adoption follows a predictable intertemporal pattern (e.g. Griliches (1957)). At first, the rate of adoption is slow. If the technology is ultimately a success, however, the rate of adoption starts to accelerate at some point. Rapid adoption continues until a substantial share of the agents have adopted the technology. At this point, the rate of adoption levels off and eventually falls. This pattern implies that the share of adopters follows a sigmoidally or S-shaped curve as a function of time, as illustrated in Figure 3.

An extensive literature spanning many disciplines has used logistic curves to model and predict growth and adoption data. The choice of a particular functional form is often somewhat arbitrary. For our application, we use a generalized logistic model proposed by Richards (1959) to fit the share of central banks that have adopted RTGS at time t, denoted by a_t. Specifically, we have

$$a_t = \frac{1}{(1 + \kappa \exp(-\gamma(t - t_{\max}))^{1/\kappa}} + \varepsilon_t \tag{1}$$

where γ is the rate at which growth initially accelerates, $t_{\max}$ is the time at which the rate of adoption is highest (i.e. the inflexion point of the curve), and κ is a shape parameter that determines whether the point of inflexion is closer to the lower or the upper asymptote.

Consistent with the stylized fact from studies on the adoption of other technologies, we find that the diffusion of RTGS also exhibits an S-shaped pattern over time. The curve of equation (1) was fitted using non-linear least squares. The estimated parameters and standard errors are given in Table 1. The actual and fitted share of central banks that have adopted RTGS are shown in Figure 5. The overall fit of the curve is good, but the time of maximum growth is estimated to be between 2004 and 2005, not 2002, as found in sample.

Prediction using our estimated generalized logistic curve suggests that the diffusion of RTGS will continue at a rapid pace until around 2010, where it will start to slow down, with the last 1% of central banks not adopting until 2020.

Rogers (1995) classifies agents into five categories that reflect their "innovativeness," or predisposition to adopt a new technology, based on how early or late they adopt relative to the median adopter, as illustrated in Figure 5. The first 2.5% of adopters (i.e. those for which the time of adoption occurs more than two standard deviations earlier than the median agent) are labeled innovators. The following 13.5% (i.e. those for which the time of adoption is between one and two standard deviations earlier than the median adoption time) are labeled opinion leaders, or early adapters. The adoption time of the last opinion leaders corresponds to the first inflection point of a bell curve (i.e. where the rate of adoption takes off). The early majority is the next 34% of adopters up to the median, while the late majority is the 34% above the median. These two majority groups reflect those agents that adopt within one standard deviation of the median agent. The remaining 16% of adopters are called laggards, or late adopters.

Roger's classification implies that central banks that adopted RTGS prior to 1987 are considered innovators. Central banks that adopted RTGS between 1986 and 1998 are opinion leaders. Central banks that adopted RTGS from 1998 through 2004 belong to the early majority and the most recent adopters are in the late majority. Interestingly, but not surprisingly, we find that all the central bank members of the CPSS belong to either the group of innovators or opinion leaders (see Table 3). Moreover, many central banks belonging to the early and late majorities explicitly cite the recommendations put forward by the CPSS as a reason for implementing RTGS.

4 Determinants of RTGS Diffusion

To identify the determinants of RTGS adoption, we thus have to consider what determines how "innovative" a particular central bank is, or, equivalently, what determines when a central bank adopts an RTGS system. In economic theories (e.g. Jensen (1982) and Jovanovic and Lach (1989)) of technology diffusion agents, usually firms, adopt a technology up to the point where the adoption cost equals the expected present discounted value of future private profits. Empirical analyses thus seek to identify the determinants of the adoption costs and the future profits. For example, Hannan and McDowell (1984) base their empirical investigation of automatic teller machine (ATM) adoption on the presumption that "an innovation will appear more attractive to a potential adopter, the greater the positive differential between profits obtainable with and without the innovation". However, as argued by e.g. Blix et al. (2003), central banking has certain features that make it quite different from the operations of private firms. Central banks tend not to operate for the single goal of profit maximization. They are instead charged with pursuing multiple and some time vague public policy goals such as monetary and financial stability as well as the smooth operation of the payment system. Moreover, central banks often face soft budget constraints that may lead to less pressure on achieving cost efficiency.

Hence, our study of RTGS adoption is importantly different from other empirical studies of technology adoption, like Griliches (1957), Mansfield (1961), Gort and Klepper (1982), Jovanovic and Lach (1989) and Skinner and Staiger (2005). These studies focus on the adoption of technologies by individuals or firms that, at least in part, have a profit incentive. Such a market incentive is only indirectly present in a central bank's decisions to adopt RTGS systems. The set of aspects taken into account by central banks when making their benefits assessment of the RTGS is potentially much bigger than that of private sector firms.

Technology is an input in the production function of payments or settlement services, just as labor and capital are. Keller (2004) highlights two key aspects of technology that are applicable in our context, as well. First, technology is a non-rival in the sense that the marginal costs for an additional agent to use the technology are Negligible and that the adoption of RTGS by one central bank does not in any way hinder another central bank from adopting. Second, the returns to technological investments are partly private and partly public.

The basic premise of our analysis is, that we assume, that a central bank, which has not yet adopted RTGS, will adopt at such time τ_i when the perceived (present discounted) value of benefits equals or exceeds the (present discounted) cost of adoption. As argued above, we do not necessarily interpret the costs and benefits here in the neoclassical sense of a profit function, but instead interpret them in the broader context of both private as well as social benefits and costs.

We regard a RTGS system to be an irreversible settlement process innovation with a considerable element of information and communication technologies (ICT) investment embedded in it. The adoption of a RTGS is hard to reverse due to the central role of the interbank payment and its many interconnections and interdependencies with other financial infrastructures. As other clearing and settlement mechanisms come to rely on instant finanlty in real time changing their modus operandi comes increasingly expensive or even infeasible. Moreover, the implementation of a specific settlement process imposes certain requirements in terms of information and communication technologies (ICT). For example, DNS requires batch-based computing and communication capabilities with participants while RTGS requires real time computing and communication.

Economic theory and evidence on technology adoption provides us with guidance on the set of potentially significant determinants of the perceived value and costs. In the rest of this section we discuss the potential determinants of innovativeness and the way we approximate for them in our empirical analysis. We limit ourselves to a brief description of the data here. The underlying details, definitions and sources are provided in Appendix A. The cost and benefit factors we identify for our empirical analysis can be classified into three groups. The first group is direct indicators of costs and benefits. The second consists of the effects that other central banks' actions have on a particular central bank's cost and benefit perception. The final group consists of indicators that are not directly related to cost or benefit.

Investment price index Our main indicator of direct adoption costs is the price of investment goods from the Penn World Table (Heston, Summers and Aten (2002)). We use this as a proxy for the price of the information and communication technology (ICT) equipment that is necessary to execute settlements in an RTGS system. Hence, we expect countries in which ICT is cheaper, reflected in a lower investment price, to adopt RTGS more quickly. We are aware that our investment price measure is not ICT specific. For this reason, we also use personal computers per capita as an additional proxy, where our main assumption is that more personal computers reflect lower ICT prices and implementation costs.

Relative size of central bank An important theme of empirical studies of technology adoption across firms is the positive effects of the size of an enterprise on its likelihood of innovating, of adopting innovations or of adopting innovations earlier (Frame and White (2004)). In this Schumpeterian view, larger sales (ceteris paribus) increase the return on technological investments, making research and development (R&D) and ultimately, adoption, more likely. Moreover, large enterprises may enjoy economies of scale or scope that make it cheaper to invest in R&D.

In the context of central banks, we also believe that size can be an important determinant, albeit for different reasons and with the opposite effect. We measure size by the number of employees and scale it by population. The relative number of employees can proxy for the nimbleness by which the central bank operates. A more efficiently run central bank is likely to be able to implement a new technology at lower cost and may be able to extract more benefits once the systems is in place.[16] For example, in Hong Kong, the same technological platform implemented for the Hong Kong dollar RTGS system has been used to set up separate systems for the U.S. dollar and the euro. This has allowed for payment versus payment settlement of foreign exchange transactions between the respective currencies and enhanced the safety and efficiency of settling these transactions in the local time zone (see BIS (2005) p. 25). High employee to population ratio could simply reflect a low relative price of labor input, however. Conceivably, a central bank could be close to the efficient frontier even if interbank payments were settled by paper checks. In this case, the benefits of adopting an electronic payment would be low, regardless of the settlement methodology employed. Moreover, a central bank like that is unlikely to have invested in technologies and knowledge that are complementary to the adoption of an RTGS system, and thus the adoption costs would be

[16] It is difficult to measure central bank efficiency (see Blix et al (2003) for a discussion). For example, the functions carried out by central banks vary significantly across countries. In fact, as noted by Brione (2006), it is hard to get an idea of the actual operating expenses of central banks, even across the OECD, let alone the rest of the world.

higher. No matter how one interprets the ratio of central bank employees to population, however, we would expect a country with a relatively big central bank, in terms of number of employees, to adopt RTGS more slowly than other central banks.

Education Brynjolfsson and Hitt (2000) provide evidence that the costs of physical capital and software are only a small part of the total costs involved in implementing ICT-related process innovations in the U.S. private sector. A large part of implementation costs have to do with the acquisition of the knowledge on how to use and benefit from the new process, which mainly involves skilled labor inputs. That is, adoption costs are lower if employees' pre-RTGS skills and knowledge help them quickly learn the best way to use RTGS systems, as pointed out in Nelson and Phelps (1966). This is often referred to as the new technology being 'appropriate' for the existing endowments (see Basu and Weil (1998) for example).

Since we use a measure education of the overall workforce in this paper, our measure also includes the skill level of the (potential) users of the RTGS system. Because of capital-skill complementaries, an RTGS system increases the productivity of educated users more than that of other users. As a consequence, we expect the benefits of RTGS to be higher in countries with a more educated workforce.

Independent of the cost or benefit interpretation of education for RTGS adoption, we expect education to have an unambiguously positive effect on the probability of a central bank adopting an RTGS system.

Financial market development On the direct benefits side, central banks themselves are not assumed to focus on the bottom line and to pursue a profit objective. They are, however, presumed to contribute to the efficiency, stability and competitiveness of domestic financial markets. The main benefit adopting an RTGS system is that it improves the efficiency of domestic financial markets, primarily by significantly reducing settlement risks.

Unfortunately, cross-country data on the amount of settlements on the interbank payment systems is not available. This means we will have to use an indirect proxy variable for the level of financial development and how it affects RTGS adoption. In all likelihood, the bigger and more developed the financial markets, the higher the potential efficiency gain from adoption, and thus, the more likely a central bank is to adopt. We approximate the size of the banking system by bank deposits as a fraction of GDP, obtained from the International Financial Statistics, International Monetary Fund (2006).

So far, we have focused on adoption costs and benefits of an RTGS system for a central bank that do not depend on the actions of their counterparts. There are, however, several reasons why the RTGS adoption decisions of central banks are likely to be interdependent.

First, the decision to adopt is influenced by competitive pressures from the global financial markets. To the extent that an RTGS system provides benefits that enhance the competitiveness of the domestic financial markets or financial assets denominated in the currency of the central bank, such pressures may speed up or force the adoption decision. For example, a prerequisite for a currency to be part of the Continuos Linked Settlement foreign exchange settlement system[17] is the ability to make real time transfers in central bank money.

Second, just as is the case for personal computers (e.g. Goolsbee and Klenow (2002)) the adoption of RTGS is subject to network externalities. That is, given the international financial integration, it is more beneficial to adopt an RTGS system for a central bank when this allows access to a broad system of other countries' RTGS systems. This consideration seems to have been an important driving force behind the E.U.'s requirement for countries to have an RTGS system in place before joining the monetary union.

Third, given the many cooperative structures set up between central banks, like the Bank for International Settlements and the European Central Bank, as well as the many other interlinkages between central banks, such as their historical linkages and international trade, it is very likely that the knowledge acquired through experiences with RTGS systems spills over to other central banks and helps them make their adoption decision. Spillovers of this type have been extensively documented as they relate to R&D and trade flows (see Coe and Helpman (1995) for an example), and they are likely to be an important factor in the diffusion of payments systems, as well.

[17] CLS Bank International is currently the leading settlement institution for foreign exchange transactions. It is an industry-owned bank, chartered in the U.S. as an Edge Corporation and supervised by the Federal Reserve System. CLS was founded in response to concerns raised by the G10 central banks about settlement risk in foreign exchange transactions. It began operations in September 2002 and now settles transactions in fifteen currencies for a sizeable share of the foreign exchange market.

Fourth, central banks do not necessarily have to install and develop the ICT component involved with the RTGS adoption themselves. Several private companies have entered the market place and have begun to offer "off-the-shelf" standardized software solutions. Currently, there are at least four providers that have built RTGS systems in more than one country.[18] The possibility of sharing development costs across customers and competition among providers has presumably lowered the cost of implementing RTGS and hence made it feasible for more countries to adopt.

The second reason above is known as a network spillover, while the third and fourth reasons are known as knowledge spillovers.[19] These are two types of indicators that we include in our analysis to capture interdependencies of central banks' RTGS adoption decisions.

Membership of international organizations To capture knowledge spillovers that arise from countries sharing information and jointly defining policy goals and standards in international organizations, we control for central banks being in members of the BIS and countries being member states of the European Union.

Assuming that membership in these organization provides earlier access to knowledge about RTGS, we expect membership in these organizations to have a positive impact on the likelihood of adopting an RTGS system.

Bilateral trade To capture knowledge and network spillovers from the countries that interact most economically, we calculate the traded weighted fraction of country's trading partners that have adopted a RTGS system.[20] This measure is very similar in spirit to the R&D spillover measure that Coe and Helpman (1995) use in their analysis and, just as in Coe and Helpman (1995), we expect it to have a positive effect on (RTGS) technology adoption.

There are two variables that we include that do not necessarily pertain to costs and benefits of adoption directly

Real GDP per capita and population Real GDP per capita seems to matter in almost all

[18] They are LogicaCMG plc of the United Kingdom, CMA Small System AB of Sweden, the joint venture of Perago Ltd of South Africa and SIA SpA of Italy and Montran Corporation of the United States.

[19] We are using the term 'spillover' here loosely. The interdepencies in the decisions of central banks that we describe are only spillovers in a pure economic sense if, when making adoption decisions, central banks do not take into account the positive effects that their RTGS adoption decisions have on their counterparts. If central banks do not internalize these effects, the rate of adoption of RTGS around the world would be inefficiently slow.

[20] We limit ourselves to the 10 largest trading partners for each country

studies of cross-country technology adoption patterns (e.g. Caselli and Coleman (2001) and Comin and Hobijn (2004)). This is probably primarily the case because real GDP per capita proxies for a set of omitted variables. Because of its high explanatory power in previous studies, we also include it in our analysis. Population mainly proxies for the size of the market. In this sense, it can be interpreted as a benefits measure.

5 Econometric Analysis

In this section we briefly outline our econometric approach. The details can be found in appendix B .Let v_{it}^* denote the perceived value of the RTGS system for central bank i at time t, and let c_{it}^* denote the cost of adoption. In practice, we neither observe the perceived benefits nor the costs of adopting an RTGS system for any central bank. However, we assume that both v_{it}^* and c_{it}^* can be represented by a linear combination of a set of observable proxy variables. These are the variables described in Section 4. We denote the vector with these variables as $\mathbf{x}_{it}$. Specifically, we assume

$$v_{it}^* = \mathbf{x}_{it}' \boldsymbol{\theta}_v + \varepsilon_{it}^v \tag{2}$$

$$c_{it}^* = \mathbf{x}_{it}' \boldsymbol{\theta}_c + \varepsilon_{it}^c \tag{3}$$

where $\boldsymbol{\theta}_v$ and $\boldsymbol{\theta}_c$ are vectors of unknown perceived marginal benefit and perceived marginal cost parameters. ε_{it}^v and ε_{it}^c are country- and time-specific random variables. The adoption time, τ_i, of RTGS for central bank i satisfies

$$\tau_i = \arg\min_t \{t \,|y_{it}^* \geq 0\} \tag{4}$$

where

$$y_{it}^* = v_{it}^* - c_{it}^* = \mathbf{x}_{it}'(\boldsymbol{\theta}_v - \boldsymbol{\theta}_c) + \varepsilon_{it}^v - \varepsilon_{it}^c = \mathbf{x}_{it}' \boldsymbol{\theta} + \varepsilon_{it} \tag{5}$$

is the net benefit of adopting RTGS at time t. We do not observe this net benefit; it is a latent variable. What we do observe is whether an RTGS system is adopted by a central bank at time t within our sample period, $\{1, \ldots, T\}$. Let y_{it} be a binary variable that equals one if central bank i

has adopted RTGS at time t and zero otherwise. As the adoption process of RTGS is still ongoing, there are two types of central banks in our sample: central banks that have already adopted - the uncensored part of the sample - and central banks that have not yet adopted - the censored part of our sample. For central banks that adopt RTGS at time $\tau_i \leq T$, we observe the binary variable $y_{it} = 0$ for all $t < \tau_i$ and $y_{it} = 1$ for $t \geq \tau_i$. This sequence of observations implies that the net benefit of adopting for central bank i was negative (i.e. $y^*_{it} < 0$) for $t = 1, \ldots, \tau_i - 1$ and positive (i.e. $y^*_{it} \geq 0$) for $t = \tau_i$. The assumed irreversibility of the RTGS adoption decision means that the observations for $t > \tau_i$ are of no empirical relevance for our analysis. For central banks in the censored part of our sample, that have yet to adopt RTGS, we observe $y_{it} = 0$ for all $t = 1, \ldots, T$. This implies that the latent net benefit was negative for every period up to time T. Following the approach of Allison (1982), we assume that ε_{it} is independently, logistically distributed, in our case across countries and over time. This allows us to write our model as a logistic hazard model[21] and to relate the probability of RTGS adoption to the cross-country and time variation in the covariates $\mathbf{x}_{it}$.

6 Results

Table 2 contains the estimated coefficients from the logit hazard rate model. Our sample covers 108 central banks from 1970 through 2000. We take an incremental approach for our analysis of the causes of technology adoption of RTGS. We start by presenting the core results for the explanatory variables that matter consistently across our model specifications. These are (*i*) real GDP per capita, (*ii*) population, (*iii*) education and (*iv*) the investment price. For all these variables, the estimated coefficients are significant and of the expected sign for all model specifications for which we have 100 countries or more. That is, larger countries, reflected by population, with a higher standard of living, reflected by real GDP per capita, and a higher level of human capital, reflected by education, seem to be more likely to adopt an RTGS system than others.

Moreover, countries with a relatively low price of capital also are more likely to adopt. Jones (1994) finds that capital prices, especially those of machines, help explain cross-country variation

[21] Our technology adoption analysis is similar to the retirement decision analysis in Ashenfelter and Card (2002).

in growth rates of real GDP per capita. Our results suggest that this variation might have to do with the way these capital prices affect technology adoption decisions. That is, if these prices seem to be significant in explaining variation in the adoption of a technology by the public sector, they most likely matter even more for the adoption of technologies by the private sector where the profit motive is a more predominant incentive for adoption decisions.

In terms of our spillovers proxies, we find that bilateral trade relationships with countries that have adopted RTGS significantly increases the probability of adoption. This is very much in line with the evidence on international R&D spillovers, as in Coe and Helpman (1995). In terms of membership in international organizations, only membership of the South African Development Council seems to function as a significant catalysts of the RTGS adoption process. A country's membership in this organization significantly increases the per period probability of adopting RTGS compared to its non-member counterparts.

Bank deposits as a fraction of GDP, our very imprecise proxy for the financial markets benefits of RTGS, does not seem to explain much of the cross-country variation in the adoption of RTGS. This is probably because this proxy does not properly capture the cross-country variation in settlement risk that is ultimately affected by the adoption of RTGS. Central bank employment to population does not seem to have a significant effect on the RTGS per period adoption probability, either.

The adoption rate of personal computers per capita does seem to positively affect the probability of adoption of RTGS. This result, however, should be interpreted with caution because the small number of observations on personal computers per capita means that it is derived with much fewer degrees of freedom than the other results.

To see how much the fitted cross-country variation in the adoption probability explains the cross-country adoption patterns, we present the results of an out-of-sample experiment in Figure 6. This figure plots the log of the fitted RTGS adoption probability, based on Model 8 from Table 2, for the countries in the censored part of our sample against the actual adoption date, as well as the '2006 or later' date for countries that had not adopted RTGS by the end of 2005. The line is the average log fitted probability of adoption in 2000 for the countries that adopt in each year. As can be seen from the figure, later adopters had, on average, a lower fitted probability of RTGS adoption in 2000.

7 Conclusion

We study the adoption of Real Time Gross Settlement systems across the 174 central banks in the world. These systems are used to facilitate interbank payments. As Frame and White (2004) point out, the rapid rate of financial innovation over the past few decades is widely recognized as a stylized fact. A striking feature of the literature based on this fact, however, is the relative dearth of empirical studies. Ours can be interpreted as one of these studies. The study of RTGS in the context of technology adoption is interesting, since the decision to adopt RTGS is in large part based on the perception by a central bank of the public goods benefit of the system, rather than on the profit motive driving the private sector.

The adoption pattern of RTGS follows an s-shaped diffusion curve, similar to that observed for other technologies in technology adoption literature (e.g. Griliches (1957), Mansfield (1961) and Gort and Klepper (1982)). The lags in the adoption of RTGS are long. In the last 20 years, the number of central banks using RTGS for their interbank payments has increased from 3 to 90. This means that 83 central banks have not yet adopted RTGS and thus are not yet reaping the efficiency gains and reduction in settlement risk provided by such a system. Estimation of the world adoption curve of RTGS suggests that it might take another 15 years before it is adopted by the remaining 83 central banks.

The probability that a country adopts RTGS in a given year increases significantly in the level of real GDP per capita. Moreover, countries with a lower relative price of capital and countries whose major trading partners adopted RTGS are also more likely adopters. This suggests that, beyond market forces reflected by real GDP and capital costs, spillovers seem to play a significant role in the adoption of this financial innovation. These spillovers seem to be transferred mainly through trade relationships. To what extent the RTGS adoption pattern, as well as its determinants, are representative of central banks' technology decisions in general is a source of further research.

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A Data: Sources and Definitions

Countries and time span: Our data cover the 174 central banks and monetary authorities listed in the 2004 Morgan Stanley Central Bank Directory 2004. The data span a time period from 1970 through 2005. The majority of the central banks in our sample serve only one country. However, the following five central banks encompass various countries: the Eastern Caribbean Central Bank, the Central Bank of West African States (BCEAO), the Central bank of Central African States (BEAC), the Bank of France and the Swiss National Bank.

Dependent variable

RTGS adoption: Dichotomous variable that indicates whether or not a central bank has implemented an RTGS system. We gathered information on each central bank's usage of RTGS, as well as the date of implementation, from publicly available websites.

Explanatory variables (alphabetical order)

Bilateral trade spillovers: Fraction of bilateral trade with top 10 trading that reflects trade with partners that have implemented RTGS. *source:* International Monetary Fund (2006) and Gleditsch (2002), *period:* 1970-2005.

BIS member: Dummy variable that indicates whether or not country is a member of the BIS. *source:* www.correlatesofwar.org, *period:* 1970-2005. Does not include members of CPSS committee.

Computers: Number of computers per 1000 people. *source:* World Bank (2006), *period:* 1980-2003.

Deposits/GDP: Bank deposits as a fraction of GDP. *source:* International Monetary Fund (2006), *period:* 1970-2004.

Education: Average primary school attainment rate. *source:* Barro and Lee (1993), *period:* 1970-2000.average over sample.

Employees/Population: Central bank employees per 1,000,000 people. *source:* Morgan Stanley (2006) and World Bank (2006), *period:* 1989-2005.average over sample.

New EU member: Dummy variable that indicates whether or not country became a member of the European Union or applied after 1986. *source:* www.wikipedia.com Union, *period:* 1970-2005.

Investment price: Capital goods price index.*source:* Heston, Summers and Aten (2002), *period:* 1970-2000.

Population: *source:* World Bank (2006), *period:* 1970-2000.

Real GDP per capita: *source:* Heston, Summers and Aten (2002), *period:*1970-2000.

SADC: Dummy variable that indicates whether or not a country is member of the South African Development Council. *source:* www.sadc.int, *period:* 1970-2005.

Note: Not all series are available for every country and every year in our sample.

B Econometric Details

The probability that central bank i adopts an RTGS system at time $\tau_i = t$ equals

$$p(\tau_i = t) = \prod_{s=t}^{T} p(y_{is} = 1|Y_{s-1}) \cdot \prod_{u=2}^{t-1} p(y_{iu} = 0|Y_{u-1}) \cdot p(y_{i1} = 0) \tag{6}$$

where Y_{t-1} denotes the set of observations up to and including y_{it-1}. However, due to the irreversible nature of the adoption decision

$$p(y_{is} = 1| \ldots, y_{iu} = 1, \ldots) = 1 \text{ for all } s > u \tag{7}$$

Hence, the only observations that are relevant for calculating the probability are the ones before the central bank adopts and the one at the time that it adopts. From Eqs. (6) and (7), we have

$$p(\tau_i = t) = p(y_{it} = 1|Y_{t-1}) \cdot \prod_{s=2}^{t-1} p(y_{is} = 0|Y_{s-1}) \cdot p(y_{i1} = 0) \tag{8}$$

In contrast, for central banks that do not adopt RTGS within our sample period (i.e. the censored part of the sample), we observe $y_{it} = 0$ for all t. We have that

$$p(\tau_i > T) = \prod_{s=2}^{T} p(y_{is} = 0|Y_{s-1})p(y_{i1} = 0) \tag{9}$$

In practice this means that, for our empirical analysis, we do not only use data on central banks that have already implemented the system, but also on central banks that have not yet done so. For the central banks that adopt, however, we will only use information up to and including the time of adoption.

From Eqs. (8) and (9), we can set up the likelihood function. Let the set of countries that have adopted RTGS by the end of the sample period be $A_T = \{i\,|\tau_i \leq T\}$. We have that $p(y_{it} = 1|\mathbf{x}_{it}) = p(y^*_{it} > 0|\mathbf{x}_{it}) = p(\varepsilon_{it} > -\mathbf{x}'_{it}\boldsymbol{\theta})$. Assuming $y_{i1}, \ldots y_{iT}$ are independent conditional on $\mathbf{x}_{i1}, \ldots, \mathbf{x}_{iT}$ and ε_{it} has a logistic distribution, $\Lambda(\varepsilon) = p(\varepsilon_{it} < \mathbf{x}'_{it}\boldsymbol{\theta})$, the likelihood function becomes

$$\begin{aligned}
\mathcal{L}(\boldsymbol{\theta};\tau_i) &= \prod_{i \in A_T} p(\tau_i = t|\mathbf{x}_{it}) \cdot \prod_{i \notin A_T} p(\tau_i > T|\mathbf{x}_{it}) \\
&= \prod_{i \in A_T} [\prod_{t=1}^{\tau_i} p(y_{it} = 0|\mathbf{x}_{it})]p(y_{it} = 1|\mathbf{x}_{it}) \cdot \prod_{i \notin A_T} \prod_{t=1}^{T} p(y_{it} = 0|\mathbf{x}_{it}) \\
&= \prod_{i \in A_T} [\prod_{t=1}^{\tau_i} 1 - \Lambda(\mathbf{x}'_{it}\boldsymbol{\theta})]\Lambda(\mathbf{x}'_{it}\boldsymbol{\theta}) \cdot \prod_{i \notin A_T} \prod_{t=1}^{T} 1 - \Lambda(\mathbf{x}'_{it}\boldsymbol{\theta})
\end{aligned}$$

Our specification implies that we can only estimate $(\boldsymbol{\theta}_v - \boldsymbol{\theta}_c)$ which will be the excess benefit from a particular variable in $\mathbf{x}_{i,t}$. However, for proxy variables for which we know or can reasonably conjecture that they either affect only costs or only benefits, the coefficient can be interpreted as the cost or benefit parameter.

The above likelihood function is that of a logit model. Since the probability of adoption can be interpreted as a hazard rate in terms of a duration model, our empirical analysis can be interpreted as discrete time duration model with logistic, time-varying hazard rates.

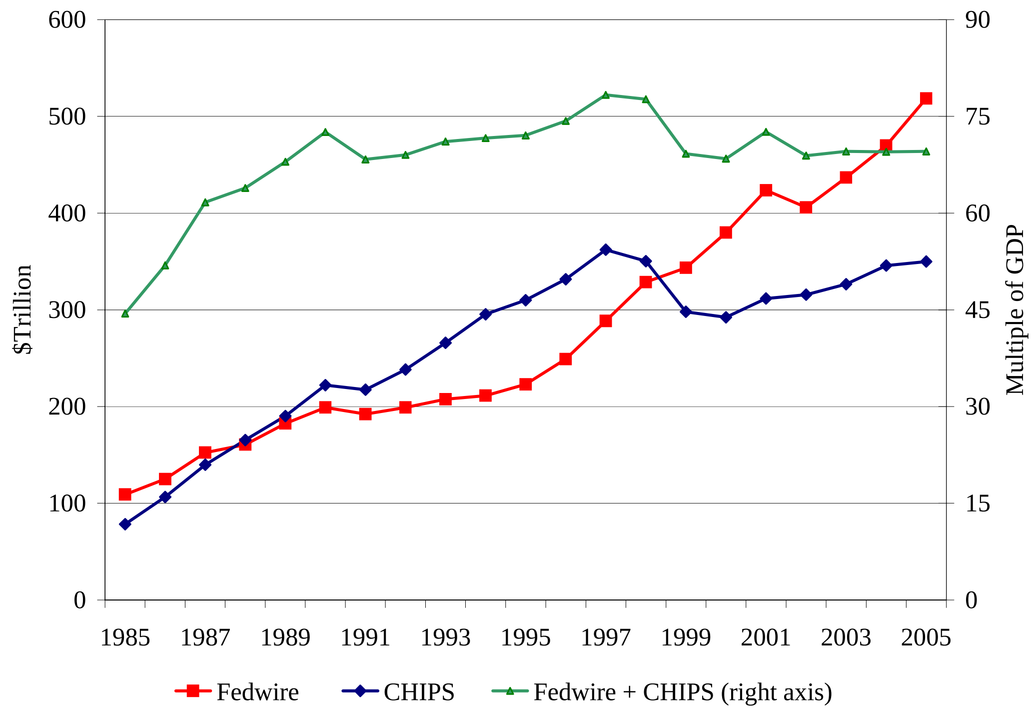

Figure 1: Value of payments settled on Fedwire and CHIPS

Table 1: Estimated coefficients for logistic adoption curve

Coefficient	$t_{\max}$	γ	κ
Value	2005**	0.25**	1.22**
Standard error	.19	0.02	0.15

** denotes significance at 5% level, * denotes significance at 10% level (both two-sided)

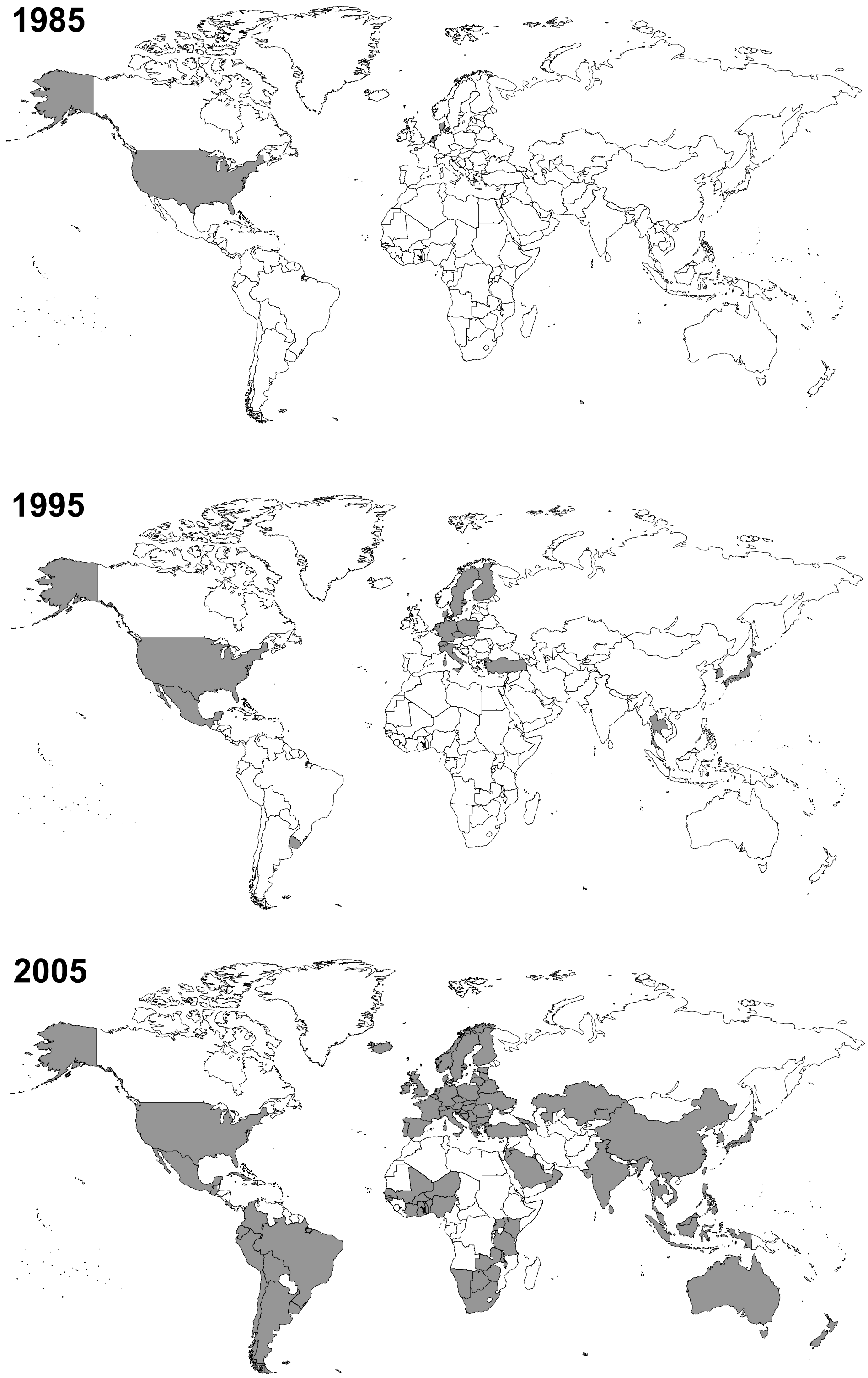

Figure 2: Adoption of RTGS in 1985, 1995, and 2005

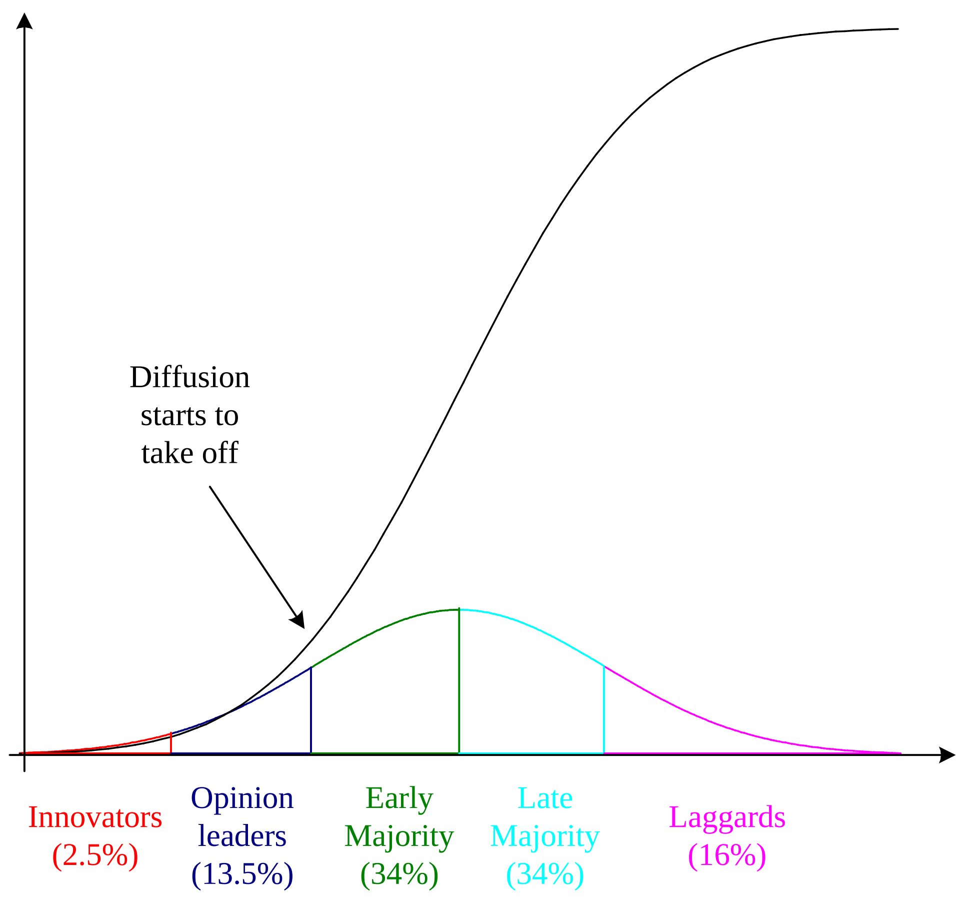

Figure 3: Stylized sigmoidal adoption curve and adopters categories

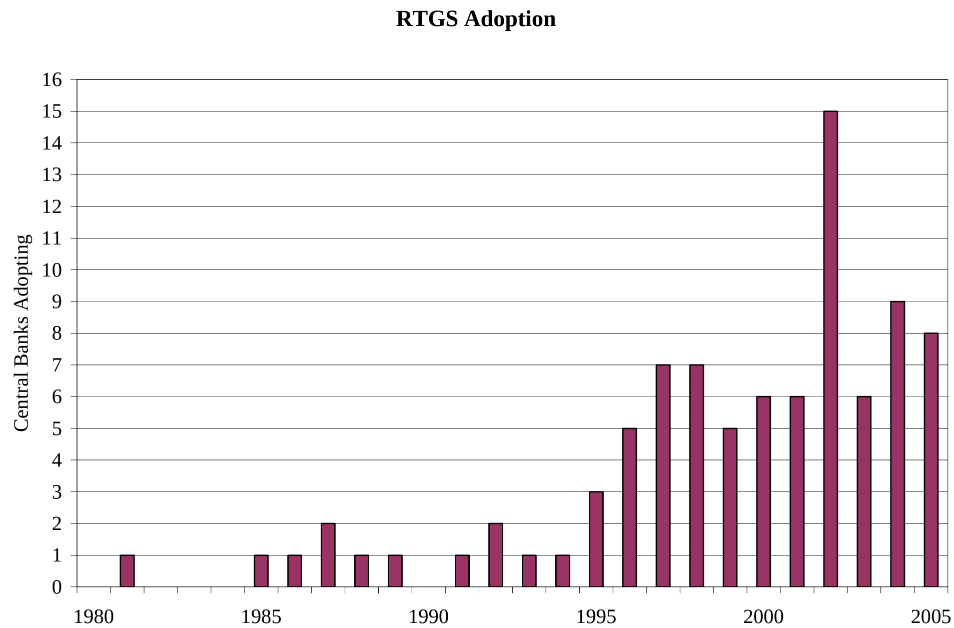

Figure 4: Annual number of central banks that adopt RTGS

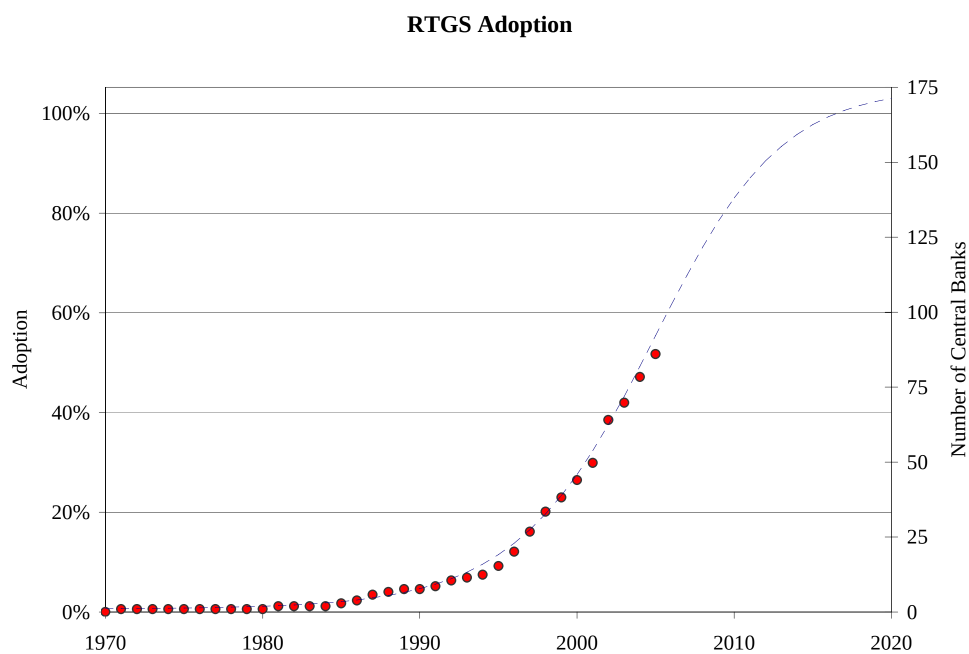

Figure 5: Actual and fitted adoption rates of RTGS (generalized logistic)

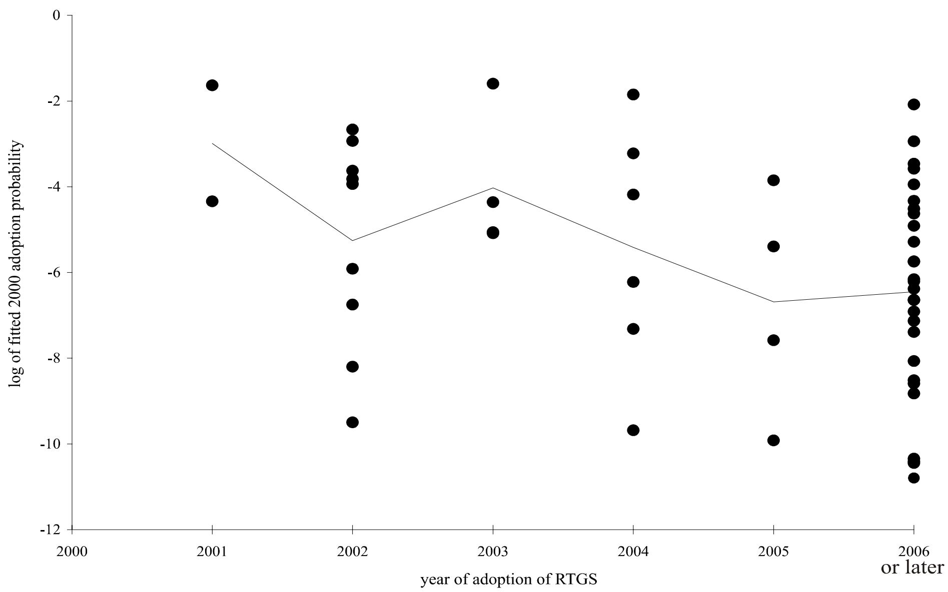

Figure 6: Fitted 2000 adoption probabilities and subsequent adoption dates

Table 2: Estimated coefficients for logit adoption model

Model	1	2	3	4	5	6	7	8
Observations	2683	2605	2683	2605	2245	694	2575	2575
Central Banks	108	105	108	105	97	90	104	104
Log Real GDP per capita	2.90**	2.55**	2.99**	2.66**	2.66**	1.75**	2.64**	2.73**
	0.40	0.42	0.42	0.44	0.47	0.65	0.43	0.45
Log Population	0.37**	0.34**	0.45**	0.41**	0.38**	0.30**	0.15	0.25
	0.11	0.12	0.12	0.13	0.12	0.14	0.18	0.18
Education	0.04**	0.04**	0.04**	0.04**	0.04**	0.07**	0.04**	0.04**
	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.02
Log Investment Price	-1.20**	-0.98*	-1.16**	-0.94	-1.35**	-1.10	-1.15*	-1.08*
	0.50	0.57	0.51	0.57	0.66	0.73	0.61	0.61
Bilateral Trade		1.86**		1.55*	1.66**	2.49*	1.83**	1.52*
		0.77		0.80	0.77	1.28	0.78	0.81
SADC			1.71**	1.41*				1.24
			0.81	0.83				0.84
BIS (not CPSS)			0.06	0.08				
			0.37	0.38				
EU			1.08*	0.78				0.79
			0.56	0.58				0.56
Deposits/GDP					-0.27			
					0.58			
Computers						0.01*		
						0.00		
CB employment/population							0.00	0.00
							0.00	0.00

** denotes significance at 5% level, * denotes significance at 10% level (both two-sided)

Table 3: Central banks that have adopted RTGS and their respective adoption dates

Central Bank	Year	Central Bank	Year
Innovators		Early Majority (continued)	
Federal Reserve System	1971	State Bank of Vietnam	2001
Danish National Bank	1981	National Bank of the Repulic of Macedonia	2001
Dutch Central Bank	1985	National Bank of Azerbaijan	2001
Central Bank of Sweden	1986	Central Bank of Bosnia and Hezegovina	2001
Opinion Leaders		Central Bank of Netherlands Antillles	2001
Central Bank of Germany	1987	National Bank of Georgia	2001
Swiss National Bank	1987	Central Bank of Costa Rica	2001
Bank of Japan	1988	Central Bank of Cuba	2001
Bank of Italy	1989	Central Bank of Brazil	2001
Bank of Finland	1991	Central Bank of Malta	2002
Central of the Republic of Turkey	1992	Central Bank of Philippines	2002
State Bank of Czechoslovakia	1992	Bank of Estonia	2002
National Bank of Poland	1993	Bank of Namibia	2002
Bank of Korea	1994	Reserve Bank of Malawi	2002
Central Bank of Uruguay	1995	Reserve Bank of Zimbabwe	2002
Bank of Mexico	1995	Central Bank of Barbados	2002
Bank of Thailand	1995	Bank of Ghana	2002
Bank of England	1996	The People's Bank of China	2002
National Bank of Kazakstan	1996	Central Bank of Jordan	2002
Hong Kong Monetary Authority	1996	Central Bank of China (Taiwan)	2002
National Bank of Belgium	1996	Central Bank of Bulgaria	2002
Bank of Portugal	1996	Bank of Botswana	2003
Bank of Spain	1997	Reserve Bank of India	2003
Central Bank of Argentina	1997	National Bank of Slovak Rebuplic	2003
National Bank of Austria	1997	National Bank of Serbia	2003
Central Bank of Ireland	1997	Central Bank of Ecuador	2003
Bank of Norway	1997	Central Bank of Sri Lanka	2003
Bank of France	1997	Central Bank Kuwait	2004
Early Majority		Central Bank of Chile	2004
Bank of Slovenia	1998	Bank of Tanzania	2004
Bank of the Republic of Belarus	1998	Central Bank of Bolivia	2004
Central Bank of Colombia	1998	Bank of Albania	2004
Monetary Authirity of Singapore	1998	Bank of Lithuania	2004
Reserve Bank of Australia	1998	Central Bank of West African States	2004
Reserve Bank of New Zealand	1998	Bank of Zambia	2004
South African Reserve Bank	1998	Central Bank of Trinidad and Tobago	2004
Croatian National Bank	1999	Late Majority	
Central Bank of Luxembourg	1999	National Bank of Romania	2005
Bank of Greece	1999	Bank of Guatemala	2005
Central Bank of Malaysia	1999	Bank of Uganda	2005
National Bank of Hungary	1999	National Bank of Ukraine	2005
Central Bank of Peru	2000	Central Bank of Montenegro	2005
Central Bank of Iceland	2000	Central Bank of Kenya	2005
Qatar Central Bank	2000	Central Bank of Oman	2005
Bank of Indonesia	2000	Central Bank of Nigeria	2005
Bank of Latvia	2000		