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ON NETWORK COMPETITION AND THE SOLOW PARADOX: EVIDENCE FROM US BANKS

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In this paper we develop a model to examine the effect of information technology (IT) in the banking industry. IT can reduce operational cost and create network externality. Empirical studies, however, have shown inconsistency, the so-called Solow paradox, which we explain by stressing the heterogeneity in banking services. In a differentiated model, we characterize the conditions to identify these two effects and explain how the two seemingly positive effects turn negative. Using a panel data set of 68 US banks over 1986–2005, our results show that the profitability effect of IT spending is negative, reflecting a negative network competition effect in the banking industry.

1 Introduction

Information technology (IT), mainly computers and peripheral equipment, has seen tremendous growth in service industries in the recent past. The most obvious example is perhaps the banking[1] industry, where through the introduction of IT-related products in internet banking, electronic payments, security investments and information exchanges (see Berger, 2003), more diverse services can be provided to customers with less manpower. Seeing this pattern of growth, it seems obvious that IT can bring about equivalent contribution to profits.

In general, existing studies have found two positive effects regarding the relation between IT and banks' performance. First, IT can reduce banks'

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[1]The IT-related innovations in the banking industry include innovations in service offering and operational function (see Morris (1986) for details). Four stages of development are identified: early adoption (1864–1945), specific application (1945–65), emergence (1965–80) and diffusion (1980–95).

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operational costs (*the cost effect*). For example, internet helps banks to conduct standardized, low-value-added transactions (e.g. bill payments, balance inquiries, account transfer) through the online channel, while focusing their resources into specialized, high-value-added transactions (e.g. small business lending, personal trust services, investment banking) through branches. Second, IT can facilitate transactions among customers within the same network (*the network*[2] *effect*) (see Farrell and Saloner, 1985; Katz and Shapiro, 1985; Economides and Salop, 1992; Varian, 2001). For example, stock exchanges and derivatives exchanges feature a network effect. As the number of buyers and sellers on an exchange increases, liquidity increases, and transaction costs decrease. This then attracts a larger number of buyers and sellers to the exchange.[3] In the case of automated teller machines (ATMs), Saloner and Shepard (1995) used data for US commercial banks for the period 1971–79, and showed that the role of the network effect is important in the ATM adoption of US commercial banks (see also Milne, 2006).

In spite of these two effects discussed above, the evidence, however, shows some inconsistency in identifying the contribution of IT to banks' profits. Some studies[4] echo the so-called *Solow paradox* in concluding that IT will actually decrease productivity. As stated by Solow (1987), 'you can see the computer age everywhere these days, except in the productivity statistics'. Shu and Strassmann (2005) studied 12 banks operating in the USA for the period 1989–97 and found that, although IT has been one of the most marginal productive factors among all inputs, it *cannot* increase banks' profits. On the other hand, there are some studies agreeing with the positive influence of IT spending to business value. Eyadat and Kozak (2005) examine the impact of the progress in IT on the profit and cost efficiencies of the US banking sector during the period 1992–2003. Their research shows a positive correlation between the level of implemented IT and both profitability and cost savings.

The inconsistency in empirical results can be attributed to differences in measurement[5] and econometric methodologies. Alternatively, the current paper attempts to provide an interpretation by stressing the heterogeneity in banking services. Indeed, compared with manufacturing industries or agriculture, banking industries present higher diversification in providing

[2]Notice that the word 'network' should not be taken literally. According to Varian (2001), a good exhibits network effects if the demand for the good depends on how many other people purchase it. Varian has denoted this network effect as the demand-side economies of scale and the cost effect as the supply-side economies of scale.

[3]http://en.wikipedia.org/wiki/Network_effect#Benefits_of_the_network_effect.

[4]Brynjolfsson and Hitt (1996) critically review this debate on the IT productivity paradox.

[5]For example, Berger (2003) pointed out two approaches in measuring productivity: either by the government productivity indexes or by a modified form of the Solow (1957) neoclassical growth model (Oliner and Sichel, 2000).

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customer services (see Section 2 for more discussion). In this case, a differentiated model with network effects would probably describe the market better than the production function approach, which has described each bank's profit (output) as a specific production function of inputs. Although most existing empirical studies[6] have adopted this approach, it can only show a mixture of IT effects on both demand and supply sides. We demonstrate that a differentiated model can distinguish a network effect (in banking services) from a cost effect, and most importantly, it can characterize the competition in the industry.

Specifically, our paper examines the effect of IT in a modified Hotelling model with network effects due to Rohlfs (1974), and then the theoretical conclusions are tested on a panel data set of 68 US banks for the period 1986–2005. The key point to understand the inconsistency is to contemplate IT's overall influence on the whole industry, and then address the equilibrium effect on individual banks. For an individual bank, it seems intuitive that both cost and network effects are positive. However, when all banks in the industry have access to the same cost-saving technology, it is natural to ask: Will the price competition in banking industries force away the cost advantage from adopting IT? Will the presence of multiple networks bring determinative benefits to individual banks in the industry? By investigating the equilibrium in a Hotelling model with network effects, we are able to explore the overall effect of IT on the whole industry.

The main findings are summarized as follows. First, we derive a simple test on the existence of the network effect by checking the relation between market share and IT expenditure. If there is only a cost effect, each bank's market share will increase with IT; however, if there is also a network effect, the market share can increase or decrease with IT. This result can be useful when a proxy variable for the size of the network is invalid. Saloner and Shepard (1995) use the number of branches possessed by a bank as a proxy for its expected ATM network size in equilibrium. Our test on the US banks shows that market share is insignificantly related to IT spending. In other words, one could conclude that the market shares are likely to remain unchanged across the industry, which could mean some banks' gain in market share could be offset by other banks' loss and this scenario reflects the case of a network effect.

Second, since the equilibrium price decreases with IT expenditure, if we can isolate this impact on prices by treating price[7] as one of the explanatory

[6]Computers may affect productivity because they are a specific capital input to the production process. This is the approach taken in most existing studies, including both the national and industry-level studies just cited, as well as studies at the plant or firm level, such as McGuckin *et al.* (1998), Stolarick (1999), Brynjolfsson and Hitt (2000) and Dunne *et al.* (2000).

[7]We provide the rationale for treating prices as explanatory variables in Section 2.

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variables in the model, then we can demonstrate that when the overall impact of IT on profits is negative, the cost effect is negative (Proposition 2). If the market share increases with IT, this negative result will reflect Berger's (2003) observation that banks may have essentially 'given away' the benefits from the technology as the industry became more competitive due to deregulation, and rents from market power shifted to consumers (see Berger, 2003, p. 142). Our estimation using data from the US banks also shows that, if prices are treated as an explanatory variable, the overall impact of IT on profits is negative, indicating that the cost-saving effect has become negative due to severe competition.

Finally, in line with both sides of the existing literature, our model predicts that banks' profits can be positively or negatively related to IT expenditure. In equilibrium, each bank's price decreases with its IT expenditure, but the impact on the profits will have to depend on whether its market share has increased. The overall effect on the whole industry, however, will depend on the relative sizes of the weighted sum of IT and the average of IT. Here, the weight is measured by each bank's market share. For the US banks, we conclude that banks' profits are negatively related to IT expenditure, showing that the weighted sum of IT is less than the average of IT. As the impact on market share is insignificant, the average IT expenditure appears to have a negative effect in influencing profitability.

Overall, a differentiated model not only fits the banking industry well, but also enables us to distinguish the network effect from demand side and the cost effect from supply side. Our empirical study on US banks shows that with each bank's higher investment in IT equipment, the benefits from cost reduction are competed away by the network competition effect, due to severe competition.

The remainder of the paper is organized as follows. In Section 2 we present the modified Hotelling model with network effects and derive testable results concerning the relation between IT and equilibrium variables. In Section 3, the theoretical conclusions are tested on panel data of 68 US banks for the period 1986–2005. Section 4 concludes the paper.

2 The Model

To deal with the observation that banks provide highly differentiated products, we adopt a simple differentiated model (due to Hotelling, 1929) with two competitive banks and infinitely many heterogeneous consumers. Some modifications are made to take into account the network externality caused by the adoption of IT (see Rohlfs, 1974; Milne, 2006). We will characterize the market equilibrium after the adoption of IT and derive three testable conclusions concerning the relation between market performance and IT expenditure.

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First of all, we quote the arguments by Chiappori *et al.* (1992) and Allen and Gale (2004) to explain how the services in the banking industry are differentiated, and why the Hotelling model is a proper setting for this industry. Chiappori *et al.* (1992) explain that there are three reasons that banking services are differentiated. First, for locational reasons their services are not perfect substitutes. Differences in size and products and specialized knowledge also make them imperfect substitutes. The second essential imperfection arises from the fact that a bank's customers have incomplete information about the services offered by a bank and the prices at which these services are offered, at the time when the relationship has begun. A third important feature is the fact that banks offer a variety of services. The simplest example of this is the case of a bank with a large number of branches. Since customers have different preferences over branch location, branches at different locations are offering different services. This means that a bank with many branches is offering a bundle of different services to its customers.

Models of spatial competition are used to represent competition among firms with differentiated products and the same can be done for the banking sector. We use the standard explanation in Hotelling's (1929) model by assuming that the consumers are heterogeneous in their preferences or their demand for banking service, and hence every bank's service is different to each consumer.

2.1 The Environment

To simplify, consider two competitive banks (A and B) in the industry, charging p^{A} and p^{B} for services, respectively. Since the diversified products in the service industry have caused a serious measurement problem (see Sherwood, 1994), the prices and outputs here are better explained as average terms, which will be explained below. There is a continuum of potential consumers indexed by x on the unit[8] interval [0, 1]. Consumers are different in terms of preferences indicated by a location in the unit interval. It is well known that when firms have to decide both the locations and prices in a Hotelling model with linear costs,[9] equilibrium does not exist. For our purpose of examining the impact of IT, we will simplify the analysis by assuming that bank A is located at 0, while bank B is located at 1.

Similar to the R&D literature (see Reinganum, 1989), we assume that, before the price competition, each bank invests e^i, $i = \mathrm{A}, \mathrm{B}$, in IT equipment. For the individual bank, the adoption of IT has two effects: to reduce the

[8][0, 1] can be interpreted as the proportion of population. Our analysis will remain the same even if we consider population growth.

[9]See, for example, Shy (1996, Ch. 7).

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operational cost and to create a network effect to customer services. For the first effect, it is assumed that the adoption of IT will cut the operational cost from c^i to $c^i - \rho(e^i)$, $i = \text{A, B}$. The cost reduction function $\rho(e^i)$ is assumed to be increasing and convex. For the second effect, we follow Rohlfs' (1974) setting in assuming that the valuation of service is positively related to the number of consumers in the same service. That is, let $V^i(e^i, e^j)$ denote the customers' valuation for consuming bank i's service. $V^i(e^i, e^j)$ is an increasing function of e^i and e^j, denoting that the rival firm's investment in IT can also benefit bank i's own service, but the effect is not as high as i's own investment. Let V_j^i denote the partial differentiation of V^i with respect to (w.r.t.) e^j; we will assume that $V_i^i > V_j^i > 0$, for $i, j = \text{A, B}$.

The timing of the game goes as follows. Before the price competition, each bank first invests e^i, $i = \text{A, B}$. Then, each bank determines its service charge (p^i, $i = \text{A, B}$). After observing the service charges, each consumer then chooses the service according to his/her valuation of service, service charges and the preference difference between him/her and the bank that provides the service. The notion we use is subgame Nash equilibrium, in which no single bank or consumer will deviate from the equilibrium decision at any stage. We will solve the equilibrium by backward induction.

2.2 Consumers

By solving each consumer's banking decision, we will be able to derive each bank's demand function. That is, for an arbitrary consumer x, $x \in [0, 1]$, the utilities for consuming each bank's service is defined by (see also Shy, 1996)

$$\begin{aligned} U^x &= n^{\text{A}} V^{\text{A}}(e^{\text{A}}, e^{\text{B}}) - (x) - p^{\text{A}} && \text{if he/she uses bank A's service} \\ &= n^{\text{B}} V^{\text{B}}(e^{\text{A}}, e^{\text{B}}) - (1 - x) - p^{\text{B}} && \text{if he/she uses bank B's service} \end{aligned}$$

The valuation of service will depend on the size of IT equipment as well as the number of consumers (n^i, $i = \text{A, B}$). The negative terms $-x$ and $-(1 - x)$ indicate the preference difference between this consumer and bank A and B, respectively. Notice that the reason for this model to be a differentiated product model is that, for each consumer, each bank's product is different, as indicated by the location of x.

Now consider an indifferent consumer $\hat{x}$, who is indifferent between consuming services from bank A or B, i.e. $n^{\text{A}} V^{\text{A}}(e^{\text{A}}, e^{\text{B}}) - (\hat{x}) - p^{\text{A}} = n^{\text{B}} V^{\text{B}}(e^{\text{A}}, e^{\text{B}}) - (1 - \hat{x}) - p^{\text{B}}$. It can be easily checked that for consumers located at $x < \hat{x}$, they will choose bank A's service; while for consumers located at $x > \hat{x}$, bank B's service will be chosen. Hence, we know that $n^{\text{A}} = \hat{x}$ and $n^{\text{B}} = 1 - \hat{x}$. Replacing n^i in the indifference condition, we have $\hat{x} V^{\text{A}}(e^{\text{A}}, e^{\text{B}}) - (\hat{x}) - p^{\text{A}} = (1 - \hat{x}) V^{\text{B}}(e^{\text{A}}, e^{\text{B}}) - (1 - \hat{x}) - p^{\text{B}}$, or alternatively

$$\hat{x} = \frac{[1 - V^{\text{B}}(e^{\text{A}}, e^{\text{B}})] - (p^{\text{A}} - p^{\text{B}})}{2 - [V^{\text{A}}(e^{\text{A}}, e^{\text{B}}) + V^{\text{B}}(e^{\text{A}}, e^{\text{B}})]} \tag{1}$$

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Note that $\hat{x}(1-\hat{x})$ also denotes bank A's (bank B's) market share, respectively, given the service charges and IT investments.

2.3 Equilibrium Prices and IT

Given each bank's demand n^{A} and n^{B}, bank i, $i=\mathrm{A}$, B, now chooses its service charge p^i to maximize its profit π^i, given by

$$\begin{aligned}\pi^{\mathrm{A}} &= \{p^{\mathrm{A}}-[c^{\mathrm{A}}-\rho(e^{\mathrm{A}})]\}\frac{[1-V^{\mathrm{B}}(e^{\mathrm{A}},e^{\mathrm{B}})]-(p^{\mathrm{A}}-p^{\mathrm{B}})}{2-[V^{\mathrm{A}}(e^{\mathrm{A}},e^{\mathrm{B}})+V^{\mathrm{B}}(e^{\mathrm{A}},e^{\mathrm{B}})]}-e^{\mathrm{A}} \\ \pi^{\mathrm{B}} &= \{p^{\mathrm{B}}-[c^{\mathrm{B}}-\rho(e^{\mathrm{B}})]\}\frac{[1-V^{\mathrm{A}}(e^{\mathrm{A}},e^{\mathrm{B}})]+(p^{\mathrm{A}}-p^{\mathrm{B}})}{2-[V^{\mathrm{A}}(e^{\mathrm{A}},e^{\mathrm{B}})+V^{\mathrm{B}}(e^{\mathrm{A}},e^{\mathrm{B}})]}-e^{\mathrm{B}}\end{aligned} \tag{2}$$

IT spending can reduce operational cost from c^i to $c^i-\rho(e^{\mathrm{A}})$, and create an extra value to bank services.

The calculation of equilibrium is standard and hence will be omitted here. The interested readers are referred to textbooks such as Shy (1996). Given $(e^{\mathrm{A}}, e^{\mathrm{B}})$ in the first stage, the market prices are

$$p^{\mathrm{A}} = \frac{[3-2V^{\mathrm{B}}(e^{\mathrm{A}},e^{\mathrm{B}})-V^{\mathrm{A}}(e^{\mathrm{A}},e^{\mathrm{B}})]+2[c^{\mathrm{A}}-\rho(e^{\mathrm{A}})]+[c^{\mathrm{B}}-\rho(e^{\mathrm{B}})]}{3}$$

$$p^{\mathrm{B}} = \frac{[3-V^{\mathrm{B}}(e^{\mathrm{A}},e^{\mathrm{B}})-2V^{\mathrm{A}}(e^{\mathrm{A}},e^{\mathrm{B}})]+[c^{\mathrm{A}}-\rho(e^{\mathrm{A}})]+2[c^{\mathrm{B}}-\rho(e^{\mathrm{B}})]}{3}$$

In particular, the price difference is

$$p^{\mathrm{A}}-p^{\mathrm{B}} = \frac{[V^{\mathrm{A}}(e^{\mathrm{A}},e^{\mathrm{B}})-V^{\mathrm{B}}(e^{\mathrm{A}},e^{\mathrm{B}})]+[c^{\mathrm{A}}-\rho(e^{\mathrm{A}})]-[c^{\mathrm{B}}-\rho(e^{\mathrm{B}})]}{3} \tag{3}$$

The demand for bank A is

$$n^{\mathrm{A}} = \frac{[1-V^{\mathrm{B}}(e^{\mathrm{A}},e^{\mathrm{B}})]-\dfrac{[V^{\mathrm{A}}(e^{\mathrm{A}},e^{\mathrm{B}})-V^{\mathrm{B}}(e^{\mathrm{A}},e^{\mathrm{B}})]+[c^{\mathrm{A}}-\rho(e^{\mathrm{A}})]-[c^{\mathrm{B}}-\rho(e^{\mathrm{B}})]}{3}}{2-[V^{\mathrm{A}}(e^{\mathrm{A}},e^{\mathrm{B}})+V^{\mathrm{B}}(e^{\mathrm{A}},e^{\mathrm{B}})]}$$

and the demand for bank B can be derived similarly. The profits after the adoption of IT are

$$\pi^{\mathrm{A}}(e^{\mathrm{A}},e^{\mathrm{B}}) = p^{\mathrm{A}}\frac{3-V^{\mathrm{A}}(e^{\mathrm{A}},e^{\mathrm{B}})-2V^{\mathrm{B}}(e^{\mathrm{A}},e^{\mathrm{B}})}{6-3[V^{\mathrm{A}}(e^{\mathrm{A}},e^{\mathrm{B}})+V^{\mathrm{B}}(e^{\mathrm{A}},e^{\mathrm{B}})]}-e^{\mathrm{A}}$$

$$\pi^{\mathrm{B}}(e^{\mathrm{A}},e^{\mathrm{B}}) = p^{\mathrm{B}}\frac{3-2V^{\mathrm{A}}(e^{\mathrm{A}},e^{\mathrm{B}})-V^{\mathrm{B}}(e^{\mathrm{A}},e^{\mathrm{B}})}{6-3[V^{\mathrm{A}}(e^{\mathrm{A}},e^{\mathrm{B}})+V^{\mathrm{B}}(e^{\mathrm{A}},e^{\mathrm{B}})]}-e^{\mathrm{B}}$$

Finally, the equilibrium levels of IT investments are determined by solving the simultaneous functions

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$$\partial\pi^i(e^{\mathrm{A}}, e^{\mathrm{B}})/\partial e^i = 0 \qquad \text{for} \quad i = \mathrm{A}, \mathrm{B}$$

IT investments are endogenously determined in the model. However, since our focus is on the relation between (equilibrium) IT and banks' (equilibrium) profits, we will not distract the readers by addressing more about the factors that affect IT investments. The related literature is the large collection of papers on IT adoption (see, for example, Cooper and Zmud, 1990; Bhatt and Grover, 2005). Also, since IT investments, prices, market shares and profits are all determined in equilibrium, to save space, we will not add in the traditional notation '*' to indicate equilibrium variables.

Overall, we have demonstrated how each bank's IT spending can influence the bank's cost, and how it can affect the demand side through the presence of network effects. As described, it might be too simplified to adopt Rohlfs' (1974) set-up, but this set-up is better for our purpose in providing clear managerial insights to the banking industries. More complicated settings allowing general settings such as considering finitely many banks or asymmetric information are referred to in Laffont *et al.* (1998).

2.4 Main Results

Here we derive some testable results concerning the impact of IT. Proposition 1 helps us to examine the existence of the network effect through checking the relation between market share and IT.

Proposition 1: (i) If we temporarily drop the assumption that V^i is increasing in e^i and hence IT has only a cost effect, then bank i's equilibrium price will decrease with e^i and market share increases with e^i. (ii) If IT has also a network effect, then bank i's equilibrium price also decreases with e^i but the market share will increase or decrease with e^i.

Proof: (i) If we temporarily drop the assumption that V^i is increasing in e^i, then IT has only a cost effect. The partial differentiation of equilibrium price w.r.t. e^i will be $\frac{-2}{3}\rho'(e^i)$. Moreover, the partial differentiation of market share (see $\hat{x}$ in (1)) w.r.t. e^i will be negatively related to the differentiation of $p^{\mathrm{A}} - p^{\mathrm{B}}$, which according to (2) is negatively related to e^i. Hence, market share must increase with IT expenditure. (ii) If IT has also a network effect, V^i and V^j are affected by e^i. The partial differentiation of equilibrium price w.r.t. e^i will be

$$\frac{-V_i^i(e^{\mathrm{A}}, e^{\mathrm{B}}) - 2V_i^j(e^{\mathrm{A}}, e^{\mathrm{B}}) - 2\rho'(e^i)}{3}$$

Moreover, since $p^{\mathrm{A}} - p^{\mathrm{B}}$ can be negatively related to e^i, the partial differentiation of market share (see $\hat{x}$ in (1)) w.r.t. e^i is not necessarily positive. Hence the market share does not necessarily increase with e^i. ■

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The significance of Proposition 1 is to provide a first-step check on the existence of the network effect. If the relation between market share and IT is negative, then it implies that there exists a network effect; but if the relation is positive, there is no unambiguous conclusion about the relation between market share and e^i. Our empirical test helps us examine this relation in the US banking industry.

The existence of network effects is not enough to judge the overall impacts of IT. We now show that it is possible to distinguish the cost effect from the network effect. Note that the overall impact of IT is a combination of price, cost and market share (demand) effects; IT has the most direct impact on cost, less direct effect on market share and least direct effect on prices. Since Proposition 1 has shown that the equilibrium price will decrease with IT expenditure, if we could isolate this price effect by treating price as one of the explanatory variables in the profit regression, then the effects will be limited on cost and market share. Moreover, since normally the service charges are given at competitive rates which are certain percentages of the overall volume of deals (i.e. mark-up), treating price as an explanatory variable is also justifiable in reality. For example, the fees charged for investment funds are usually 1.5 per cent of the total amount. After treating the prices as explanatory variables, we can show that the market share will increase with IT. Therefore, if the relation between profits and IT is negative, then we can conclude that the negative network competition effect via price has dominated the positive cost advantage.

Proposition 2: If the impact on prices is isolated, when IT has a negative effect on profits, the network competition effect is higher than the cost effect.

Proof: Given p^{A} and p^{B} as exogenous, the partial differentiation of $\hat{x}$ in (1) w.r.t. e^{A} is

$$\frac{\begin{array}{c}-V_{\mathrm{A}}^{\mathrm{B}}(e^{\mathrm{A}},e^{\mathrm{B}})\{2-[V^{\mathrm{A}}(e^{\mathrm{A}},e^{\mathrm{B}})+V^{\mathrm{B}}(e^{\mathrm{A}},e^{\mathrm{B}})]\}\\ +[V_{\mathrm{A}}^{\mathrm{A}}(e^{\mathrm{A}},e^{\mathrm{B}})+V_{\mathrm{A}}^{\mathrm{B}}(e^{\mathrm{A}},e^{\mathrm{B}})]\{[1-V^{\mathrm{B}}(e^{\mathrm{A}},e^{\mathrm{B}})]-(p^{\mathrm{A}}-p^{\mathrm{B}})\}\end{array}}{\{2-[V^{\mathrm{A}}(e^{\mathrm{A}},e^{\mathrm{B}})+V^{\mathrm{B}}(e^{\mathrm{A}},e^{\mathrm{B}})]\}^2}$$

which is positive. Since $\hat{x}$ is positively related to e^{A}, it is easy to see from the definition of π^i that, if IT has a negative effect on profits, then the network competition via the price effect is higher than the cost effect. ■

Finally, in line with both sides of the existing literature, we predict that banks' profits can be positively or negatively related to IT expenditure. The overall impact consists of effects on prices, cost and market share (demand). For the individual bank, Proposition 1 has shown that equilibrium prices will decrease with IT. Next, the cost effect is a combination of two parts: IT expenditure as cost, and the reduction of operational cost due to IT. This

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term could be positively or negatively related to IT, depending on whether the reduction on the operational cost is competed away in the market competition. Lastly, we have proved in Proposition 2 that, if the price effect is isolated, IT has a positive impact on market share. However, since equilibrium price will be decreasing in IT, through the definition in (1), there is no conclusive result concerning the effect on market share.

Moreover, although the valuation of consumer service will change with IT, the total size of consumers is fixed (i.e. restricted to the unit interval). If one bank's market share increases with IT, the other bank's market share cannot increase simultaneously. Since the empirical tests are examined with bank-level data, it is useful to recall from the basic econometric text about the sign for the parameter of IT in the regression. That is, if we run the regression of profits (π^i) on IT expenditures (e^i), the sign for the parameter of IT will depend on whether $\Sigma\left(\pi^i - \overline{\pi^i}\right)\left(e^i - \overline{e^i}\right) \gtrless 0$, where $\overline{\pi^i} = \Sigma\left(\pi^i/n\right)$ and $\overline{e^i} = \Sigma\left(e^i/n\right)$. After rearranging, this condition becomes

$$\sum \frac{\pi^i}{\sum \pi^i} e_i - \sum \frac{e^i}{n} \gtrless 0 \tag{4}$$

Here n denotes the number of sample banks. In other words, the overall effect on the whole industry will depend on whether IT can change the relative sizes of the weighted sum of IT and the average of IT. If there are scale economies in adopting IT, then the sign in (4) will be positive. Berger (2003) observed that, in the USA, although large banks have significant scale economies with back-office operations (cost reduction), small banks are often able to share in the benefits of technological progress (network effect). The overall impact on profits in the industry is therefore ambiguous.

3 Empirical Study

The purpose of the empirical study is to see how the differentiated model above can help us understand the overall impact of IT on commercial banks in the USA. The data consist of a panel of 68 US banks for the period 1986–2005. Since most existing research on US banks has adopted the production[10] function approach, it is not easy to distinguish the network effect from the demand side and the cost effect from the supply side, or to characterize the effect from competition in this highly diversified industry. Our theoretical discussion above directs us with three steps to unravel the overall impacts.

First, we can check the existence of the network effect by examining the relation between market share and IT. According to Proposition 1, we will test the following empirical models, where the subscripts denote time t for the period 1986–2005.

[10]See Shu and Strassmann (2005) for a review.

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$$x_t^i = \beta_0 + \beta \mathrm{IT}_t^i + \varepsilon_t^i$$

where IT_t^i and x_t^i denote bank i's IT expenditures and market share at time t. Note that we have replaced e_t^i with IT_t^i to make a clear distinction from the error term ε_t^i. The equation tests if there is a network effect: if β is negative, then there is a network effect, but if β is positive, then nothing conclusive can be said about its existence.

Second, in order to distinguish the cost effect from the network effect, we isolate the price effect by treating prices as one of the explanatory variables in the profit regression, and test the following model:

$$\pi_t^i = \delta_0 + \delta p_t^i + \gamma \mathrm{IT}_t^i + \eta W_t^i + \mu O_t^i + \varepsilon_t^i$$

where W_t^i and O_t^i denote bank i's non-interest expenditures and other operating expenditures at time t. If γ is negative, then following Proposition 2, we can conclude that the cost effect is negative.

Third, we test the overall impacts of IT on profits, by testing the following model, having controlled for the two key bank-specific expenditure variables:

$$\pi_t^i = \sigma_0 + \lambda \mathrm{IT}_t^i + \phi W_t^i + \theta O_t^i + \varepsilon_t^i$$

If λ is negative, then the overall impact (cost effect and network effect) of IT is negative; if λ is positive, then the overall impact of IT is positive.

Further, we also consider the same set of regression specifications for two subperiods (i.e. 1986–95 and 1996–2005) to examine possible changes in the coefficients. The justification for this subperiod analysis is given as follows. According to Gordon (2002), the early IT-based innovations have been historically grouped into four distinct periods: early adoption (1864–1945), specific application (1945–65), emergence (1965–80) and diffusion (1980–95) periods. Since the late 1970s, there have been major changes in the regulatory regime affecting banks operating in the USA particularly in terms of expansion of bank powers and liberalization of interstate banking and branching rules. Legislation passed by the federal government during the 1980s has diminished the distinctions between banks and other financial institutions in the USA. The major impact of the tremendous deregulation, beginning in the early 1980s, has been a greater degree of consolidation of the banking industry, partly as a consequence of elimination of financially unsound banks. Such banking revolution in the mid-1980s has brought in information technologies in banking, ending the rule of the traditional high street bank. Since 1996, the USA has experienced the major era of branching deregulation, the introduction of surcharges at ATMs (in 1996) and the evolution away from shared, nominally non-profit, ATM networks to publicly owned, for-profit payment networks. So the starting point of our hypothesis examining the role of IT is appropriate and it appears that the big

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IT spending took place in the first 10 years of such a revolution (1986–95—pre-IT revolution) and subsequently the IT investment might have saturated—the second subperiod (1996–2005—post-IT revolution). We will estimate our regressions for the two subperiods to show how the effect of IT might have changed instead of being constant for the whole sample.

Also, to consider the change in market structure, we calculate an index similar[11] to the Herfindahl–Hirschman index (HHI). Recall that x_t^i is the market share for firm i (the details of its measurement are given below). The index is defined as

$$\mathrm{HHI}_t = \sum \left(x_t^i\right)^2$$

Having calculated this index for our data set, we find that the rates of change in this index over the two subperiods are nearly the same (on average). However, the absolute values do indicate a higher degree of market concentration in the post-IT-diffusion period. We will use this index as an instrument variable in the profit regression.

3.1 Data Source and Discussion

All the data have been extracted from Company Accounts in the Worldscope database in Datastream. The definitions of the variables are as follows.

π_t^i: *Net revenue* represents the total operating revenue of company *i*.
IT_t^i: *IT expenditure* represents equipment expenses by bank *i*, excluding depreciation cost. Since there are no exact data for IT in the bank-level company data set we have used, we need a proxy for this variable. As the banking industry is a service industry, a big part of the equipment spending in a bank is indeed IT related. Hence, we use equipment expenses by each bank as a proxy for IT.
x_t^i: *Market share* is calculated as the share of bank *i*'s revenue over the total revenue of the banking industry (in this case 68) and multiplied by 100.
p_t^i: *Average price* is calculated as bank *i*'s interest expense over net revenue. Interest expense represents the total amount of interest paid by the bank. In the banking industry, the IT value-added activity helps to effectively generate funds from the customer in the form of deposits. Profits then are generated by using deposits as a source of investment funds (Chen and Zhu, 2004). In this sense, price should reflect interest expenses incurred by the bank to procure these funds.

It is worth noting that, due to the heterogeneity and multiple product properties of bank service, it is difficult to find a conclusive method to measure output (and price) in a service industry (see Sherwood, 1994). In the

[11]The original HHI is a summation over the whole industry, but since our sample covers only 68 large banking firms, the index we calculate is not the HHI in the original definition. However, we still use HHI to indicate the index for concentration.

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banking industry, banks provide various services including internet banking and credit loans. All these services could involve different qualities and even several services bundled in a complex way. Nevertheless, we need a proxy for average price to examine the network effect of IT. Hence, we consider interest expense data that mainly comprise what a bank pays to its depositors and other borrowing obligations. All these interest expenses plus a mark-up (or interest margin) will be equal to interest revenue. This mark-up or margin will depend on its level of IT investment, or in other words, IT investment can influence this mark-up. So our interest expense per unit of revenue as a proxy for the cost side of the pricing is an appropriate measure of an average price for the multi-product services that a bank offers.

W_t^i: *Non-interest expenditure* includes both labour and non-labour expenses. If non-labour (or capital-related) expenses exceed the labour cost, then this variable can have a positive impact on banks' revenue.
O_t^i: *Other operating expenses* have been used as another control variable in the regressions. This is expected to have a negative impact on banks' revenue.

As the above variables are collected from one single database, an important methodological issue relating to data comparability that normally arises with IT data has been resolved. As is well known, the US banking industry has undergone major structural changes with frequent mergers and acquisitions and, consequently, all banks do not have extensive historical expenditure data. Therefore, our sample only covers 68 banks which have data for a relatively longer time period. The banks in our sample have an average of \$2.2 billion in terms of revenues and \$72 million in terms of average equipment investment. Shu and Strassmann (2005) discuss several problems associated with IT-related data either from the US Bureau of Economic Analysis or from other government agencies. Thus, researchers have used different sets of IT spending data, e.g. the data from the International Data Group survey on about 300 companies. But, the reliability of such a data set is still questionable because it used mail-in questionnaires or telephone surveys which are either incomplete or from interpretations that deal more with the views of the respondents than the facts. We chose the banking industry because it is part of the service industry that has been suspected of having one of the lowest IT productivity. Thus, the objective of this paper is to analyse the banking industry using bank-level data on equipment expense with reasonably long time dimension as a suitable proxy for IT spending.

3.2 Empirical Results

The aim is to investigate whether IT investments improve banks' profitability. Based on the above framework, we estimate the contribution of *bank-level* equipment investment in IT to the financial performance of banks. The cross-sectional and time-series nature of the available data (68 banks for a

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Table 1
Panel Regressions for Market Shares (x_t)

	Market shares (x_t)				
Dependent variable	*Model 1*	*Model 2*	*Model 3*	*Model 4*	*Model 5*
Constant	1.395**	–0.373	–0.357*	2.448**	1.014
	(0.109)	(0.209)	(0.172)	(0.681)	(9.174)
IT_t	0.016	0.04	0.038	–0.095	–0.103
	(0.011)	(0.024)	(0.021)	(0.071)	(0.931)
x_{t-1}	—	0.981**	0.983**	—	0.968**
		(0.012)	(0.029)		(0.175)
Instruments	—	—	—	p_t	p_t; p_{t-1}
Adjusted R^2	0.844	0.964	0.964	0.918	0.958
Banks	68	68	68	68	68
Observations	1293	1225	1225	1293	1225

Notes: Figures in parentheses are standard errors. * and ** indicate a significance level at the 5 per cent and 1 per cent level, respectively. Model 1: bank-specific fixed effect; Model 2: bank-specific random effect; Model 3: period fixed effect (time dummy variables); Model 4: two-stage FGLS (cross-section fixed effects); Model 5: two-stage FGLS (period fixed effects). IT variable is expressed in logs.

time period of 20 years) allows us to make use of a sufficiently broad sample dimension, giving a pooled total sample of 1293 observations. The parameters that are to be estimated are assumed to be constant across banks and over time, as is common with a regression model. Except for market share and average price (which are expressed in terms of ratios), all other variables are measured in logarithms to adjust for heteroskedasticity and to detrend the variables measured in different units in terms of US$; thus the coefficients measure the elasticity of prices, market shares and profits. The estimation has been carried out using panel regression methods in Eviews.

We run different methods of estimation for checking robustness of the parameters. All estimations in Tables 1–4 have been undertaken using feasible generalized least squares (FGLS) with fixed and random effects. FGLS can correct for heteroskedasticity in a panel data set. In panel data models, there are different types of specification bias which can produce biased estimates of the coefficients if estimated under the classical ordinary least squares assumptions. The two key biases are induced by the presence of unobserved heterogeneity across different cross-sections (i.e. banks in this case) and the possible endogeneity of the explanatory variables. So we are correcting for both the problems. Moreover, there could be endogeneity in the regressors as price could be an endogenous variable. Since we have formulated the regression model according to our theoretical results (hence we cannot remove any variable *ad hoc*), we have tried to correct this correlation problem through econometric methods. Specifically, we are using FGLS that are designed to correct for ordinary least squares problems caused by relationships between the cross-sectional units. Such errors are common when there are many cross-sections. This approach is designed to guard against this heterogeneity,

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TABLE 2
PANEL REGRESSIONS FOR BANK PROFITS (π_t)

	Model 1	*Model 2*	*Model 3*
Constant	0.052	–0.259**	–0.138
	(0.079)	(0.077)	(0.439)
p_t	1.365**	1.797**	1.246**
	(0.043)	(0.053)	(0.194)
IT_t	–0.017**	–0.099**	–0.103**
	(0.005)	(0.014)	(0.035)
W_t	1.202**	1.394**	1.226**
	(0.024)	(0.035)	(0.257)
Q_t	–0.167**	–0.293**	–0.096
	(0.022)	(0.028)	(0.231)
Instruments	—	—	x_{t-1}; IT_{t-1}; C_t; H_t
		Hausman test: $\chi^2(4) = 139.02$ (p value = 0.00)	
Adjusted R^2	0.99	0.98	0.99
Banks	68	68	68
Observations	1293	1293	1225

Notes: Standard errors are in parentheses. ** indicates a significance level at the 1 per cent level. Panel bank-specific fixed effect. IT_t, W_t and O_t have been used in logs; W_t and O_t are control variables. Model 1: FGLS cross-section fixed effect; Model 2: FGLS period random effect; Model 3: two-stage FGLS cross-section fixed effect.

TABLE 3
PANEL REGRESSIONS FOR BANK PROFITS EXCLUDING PRICES

	Model 1	*Model 2*	*Model 3*
Constant	0.962**	0.764**	0.742**
	(0.112)	(0.094)	(0.097)
IT_t	–0.10**	–0.09**	–0.10**
	(0.027)	(0.018)	(0.019)
W_t	1.175**	1.232**	1.256**
	(0.065)	(0.047)	(0.048)
Q_t	–0.10**	–0.155**	–0.168**
	(0.054)	(0.038)	(0.038)
			Hausman test: $\chi^2(3) = 14.779$ (p value = 0.00)
Adjusted R^2	0.964	0.988	0.967
Banks	68	68	68
Observations	1293	1293	1293

Notes: Standard errors are in parentheses. ** indicates significance at the 1 per cent level. Panel bank-specific fixed effect and period-specific random effect. IT_t, π_t, W_t and O_t have been used in logs. Model 1: cross-section weights (panel corrected standard errors) ordinary least squares; Model 2: FGLS period fixed effect; Model 3: FGLS period random effect.

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Table 4
Subperiod Panel Regressions for Market Shares and Profits

	Market shares (x_t)		Profits (π_t)	
Dependent variable	*1986–95*	*1996–2005*	*1986–95*	*1996–2005*
Constant	–0.367	–0.359	0.072	0.712**
	(0.296)	(0.217)	(0.087)	(0.097)
p_t	—	—	1.53**	1.26**
			(0.039)	(0.04)
IT_t	0.039	0.038	–0.023**	–0.01**
	(0.038)	(0.025)	(0.007)	(0.005)
W_t	—	—	1.251**	1.086**
			(0.027)	(0.019)
O_t	—	—	–0.227**	–0.095**
			(0.026)	(0.014)
x_{t-1}	0.976**	0.986**	—	—
	(0.050)	(0.038)		
Adjusted R^2	0.96	0.97	0.99	0.99
Banks	68	68	68	68
Observations	545	680	613	680

Notes: Figures in parentheses are standard errors. ** indicates a significance level at the 1 per cent level. All estimations are carried out using FGLS bank-specific fixed effect and period random effect (cross-section and time dummy variables). IT_t, W_t and O_t have been used in logs; W_t and O_t are control variables.

with unequal unit error variances. Second, we are using instrumental variable methods to correct for endogeneity in the regressors (particularly the price variable here). In Table 2, where price enters as an explanatory variable, we have instrumented with other exogenous variables that could act as instruments to explain price endogeneity which in turn influences bank profits. We have done this in Table 2 (Model 3) to check for robustness of estimates in the profit regression.

In Table 1 we have considered five models. Model 1 runs FGLS considering the bank-specific fixed effect; Model 2 runs FGLS considering the bank-specific random effect; Model 3 runs FGLS considering the period fixed effect (time dummy variables); Model 4 runs 'two-stage' FGLS considering cross-section fixed effects; Model 5 runs 'two-stage' FGLS considering period fixed effects. As these estimation methods are now standard, we will ignore the detailed discussion and discuss briefly citing Wooldridge (2002) for full description of the technical details about each method. The presence of cross-section and period-specific effects can be handled using fixed or random effects methods. The bank-specific effect could be either an intercept that varies for each cross-sectional unit in the panel (i.e. fixed effect) or a random variable drawn from a common distribution with mean and variance (i.e. random effect). There could be another problem that strict exogeneity of the regressors is required w.r.t. the error term. Consequently, if any of the right-hand-side variables at a given time period is correlated with the error term, then the fixed effect or random effect estimators are inconsistent. Thus

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estimating via FGLS specifications takes account of panel heteroskedasticity and contemporaneously correlated errors. Further, some regressors may be jointly endogenous with the dependent variable despite the assumption of strict exogeneity, so we use instrumental variables techniques as in Models 4 and 5 in Table 1 to take account of possible endogeneity.

The FGLS estimation results for market share appear in Table 1, whereas Tables 2 and 3 present results drawing inferences for bank profits, uncovering network effects and the role of competition. It is apparent from results in Table 1 that the market share is insignificantly related to IT spending across all the different methods of estimation, even after having taken account of any possible dynamics via including a lagged term of the market share. In other words, one could conclude that the market share is likely to remain unchanged across the industry, although it could mean some banks' gain in market share could be offset by other banks' loss. This scenario reflects the case of a network effect. Overall, the results support our theoretical notion of a possible network effect derived in the propositions. The magnitude of the IT term remains nearly stable around 0.1 across different methods of estimation in Tables 2 and 3, even when we drop the price term. The overall performance of estimates in Tables 2 and 3 is satisfactory. The relationship between the dependent variables and the independent variables in the three different models is strong, with the t values significant at a 1 per cent level in each model. The values obtained for R^2 are satisfactory, as they are fairly high.

To distinguish the network effect from the cost effect, in Table 2 we present the revenue effects of IT spending, after having controlled for the effects of average price, non-interest expenditure and other operating expenses. We find consistently a negative effect of IT on revenue and the result is robust across different estimation methods (see Table 2). Model 3 in Table 2 (two-stage generalized least squares) is formulated with the lagged market shares and lagged IT as instruments along with capital expenditure as per cent of total assets (C) and HHI (H) as the four instruments to satisfy the order condition in the two-stage generalized least squares. The coefficients are of similar magnitude as theoretically predicted in the model.

Finally, to estimate the overall impact of IT, we have omitted average price as a regressor from the profit regression and estimated the effect of IT on bank profits (see Table 3). The estimates reported in Table 3 further support the robustness of our estimates. In all cases the coefficients remain significantly different from zero. The negative effect of IT on profit still holds, indicating the presence of a network effect, in the sense that some banks benefit from more customers, while others are actually losing their customers.

Given the longer time dimension, we now run the regressions for the two subperiods discussed earlier in order to capture any change in the coefficients in each of the two key equations. The results are presented in Table 4.

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In both periods, market shares remain insensitive to IT spending, whereas bank profit for the industry does not increase in response to higher IT spending. The magnitude of the IT coefficient in the profit equation improves marginally in the second period relative to the first period. This improvement suggests that the cost effect is higher than the network effect in the second period according to Proposition 2, also indicating the benefit from a higher degree of market concentration as observed in the HHI variable. Going forward, this implies that there could be a point where profits no longer negatively respond to increases in IT expenditure because the negative network effect from competition is exactly offset by the cost advantage from IT, thus producing a neutral or insignificant effect on profit. The coefficients associated with non-interest expenses and operating expenses have been in line with expectations. The positive coefficient associated with non-interest expenses suggests that, in the banking industry, more IT requires more highly skilled labour, which, although it comes at higher wages, with higher labour productivity it contributes to higher profit. Also non-labour expenses could contribute to higher capital productivity, thus justifying the positive coefficient associated with non-interest expenses. But the negative coefficient associated with other operating expenses suggests operational efficiency.

Overall, our results are consistent with the testable implications of the theoretical propositions derived in the previous sections.

1. Market share remains insignificant with higher levels of IT, reflecting the possibility of a network effect.
2. Prices contribute positively to firm profitability and there exists a negative relation between IT investment and bank profits.
3. Banks with higher levels of IT have lower profitability due to the possibility of a network competition effect, and the impact remains consistently negative across different methods of estimation, even if price as a control variable is not considered. This means that profit from cost reduction is not sufficient to offset the loss from the negative network competition effect, making the overall effect of IT on revenue negative, although the magnitude of the effect is small.

This study contributes to the understanding of how IT contributes to the banking industry in the USA or the service industry in general. Prior research has linked IT to productivity, while this research provides evidence that IT is also related to profitability. Our results are also consistent with prior assertions that IT innovations could create network effects but this may not be easily captured in the productivity approach adopted in previous studies. Thus our results do lend evidence that IT can have a negative effect on profitability and the consistency across different methods of estimation gives us greater confidence in our results. Beccalli (2007) also finds that although banks are the major investors in IT there is little relationship between total IT investment and improved bank profitability or efficiency,

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indicating the existence of a profitability paradox. In our paper, we explain this paradox via emphasizing the competition effect of IT investment both theoretically and in an empirical sense.

4 Conclusion

This paper is concerned with the impact of IT on the banking industry, as banks are the intensive users of IT. The usage of IT can lead to lower costs, but the effect on profitability remains inconclusive owing to the possibility of network effects that arise as a result of competition in financial services. The paper analyses both theoretically and empirically how IT-related spending can affect bank profits via competition in financial services that are offered by banks. The paper uses a Hotelling model to examine the differential effects of the IT in moderating the relationship between costs and revenue. The impact of IT on profitability is estimated using a panel of 68 US banks over 20 years. Panel econometric techniques are used to examine the differential impact of IT on market share and profits. The results document the role of IT on the cost and revenue in banking and show the impact of network effects on bank profitability. While IT might lead to cost saving, we show that higher IT spending can also create network effects lowering bank profits. Besides, IT spending has an insignificant effect on market share.

The relationship between IT expenditures and bank's financial performance or market share is conditional on the extent of the network effect. If the network effect is insignificant, IT expenditures are likely to (i) reduce payroll expenses, (ii) increase market share, and (iii) increase revenue and profit. The evidence, however, suggests that there is a significant network effect in the US banking industry, implying that, although banks use IT to improve competitive advantage, the net effect is not as positive as normally expected. In a broader context, the innovation in IT, deregulation and globalization in the banking industry could reduce the income streams of banks, and thus the strategic responses of the banks, particularly the trend towards mega-mergers and internal cost cutting, could change the dynamics of the banking industry. Given our negative result due to a possible network effect, the ongoing changing banking environment can still make it insufficient to offset any reduction in revenue.

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