4. Adoption and diffusion of e-business and the role of network effects*

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4.1 INTRODUCTION

The Internet is an essential part of the infrastructure of the Information Society. It already facilitates a myriad of new possibilities and opportunities to assist and run businesses differently from what we know from the past. Proprietary systems facilitated enterprise resource planning in the 1980s and 1990s, but these systems operated in stand-alone settings. Today these systems are largely replaced by open standard software and what is more, they are connected through networks. It is mainly because of the open standards that many firms have been able to adopt the Internet at low prices and that information can be easily shared. Especially when this information is fed into new communication standards like XML then the communication becomes very smooth and rich (see e.g. Lucking-Reiley and Spuilber, 2001). Developing such protocols requires extensive cooperation of buyers and sellers within industries and organizations like RosettaNet support the development of (open) e-business standards.1

What we see now is just the beginning of e-business, e-commerce or e-government. However, if we take the long-term view, not only communication about goods, but also the production process itself, will be embraced by this extremely pervasive innovation process. This will happen relatively slowly and its path is difficult to predict because the high degree of complementarity with other developments and applications of information technologies.

It is a well-established view that investment in ICT as such has little impact on productivity and firm performance. Firms need to adjust their internal organization, re-establish competences and responsibilities and re-negotiate and re-discuss contracts and agreements upstream and downstream of the value chain. So gains from investment in ICT will emerge if

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these investments are accompanied with investments in the internal and external organization. Because of their very nature, this adjustment process is slow and it takes considerable time before efficiency gains are reported.\textsuperscript{2} Investigation of productivity effects of ICT investments over time typically shows an inverse U-shaped effect. In the early years after adopting new technologies, the productivity increases, but only marginally. After some years the productivity effects become more sizeable and in the final stage the growth rate of productivity due to ICT investments evaporates (see e.g. Brynjolfsson and Hitt, 2000 and Gretton et al, 2004). The main message however remains the importance of workplace reorganization for successful adoption of e-business practices.

Adopting the Internet by firms is positively related to expected market gains (improving the quality and variety of products, improving customer relations and increasing market presence and sales), expected internal cost reduction and expected improved position on the market for inputs. (Hollenstein, 2004). Hollenstein finds, using Swiss-based firm level data, that obstacles for investing in and using ICT for e-business are investment costs and lack of know-how (lack of ICT personnel, information and management problems), and in the case of the adoption of e-sales practices, technological uncertainties also appeared to be obstacles. Concerning firm size and the adoption of ICT, Internet technologies and e-business, Hollenstein (2002) finds that in general larger firms adopted ICT technologies and the Internet earlier than smaller firms – which is to be expected – but also that the intensity of Internet use is larger for medium-sized firms. This indicates that intra-firm diffusion matters and that larger firms adopted ICT and the Internet earlier, but also that it takes more time for them to use these technologies to the full extent. This implies that medium-sized firms face fewer obstacles, or expect to have higher revenues, in intra-firm diffusion of ICT and Internet use. Next to direct investment costs, workplace reorganization and lack of qualified personnel are the main determinants for this difference between large and small firms. Hollenstein (2002), for instance, finds that there is a lack of potential using ICT among smaller firms whereas larger firms face more information and management problems.

In terms of different usage of ICT, using the Internet has shown the fastest rate of adoption. For instance Maliranta and Rouvinen (2004) report that (almost) none of the Finnish firms used the Internet in 1992 whereas it was almost 100 per cent in 2001. Also the use of email has increased remarkably sharply from 20 per cent in 1992 to almost 100 per cent in 2001. The use of communication technologies for electronic data interchange (EDI) also grew in this period but not that spectacularly, from 20 per cent in 1992 to 50 per cent in 2001. One should realize that the concept of EDI was already established in the 1970s and that different
communication protocols were used to communicate with upstream and downstream firms. The emergence of the Internet as a more standard communication medium has increased the use of EDI considerably. The usage of Extranet and Intranet technologies (and practices) increased in the period 1992–2001 from 0 to 50 per cent and 0 to 70 per cent, respectively (all data from Maliranta and Rouvinen, 2004). Concerning firm size and the use of ICT, large firms are in general found to adopt Internet and related technologies first whereas smaller firms are the laggards (Clayton et al., 2004). However, e-business practices such as EDI are still mainly done over non-Internet networks by large firms whereas EDI over the Internet is equally developed and diffused among small, medium and large firms (Clayton et al., 2004, p. 244). This suggests that the introduction of the Internet has increased the profitability of medium and small firms to invest in e-business practices and that large firms still stick to the more traditional communication media.

Finally, concerning ICT investments per employee, Becchetti et al. (2003) find that small firms invest per employee twice as much in ICT as larger firms. Disentangling total ICT investment into various components it appears that this finding is driven by hardware and software investments. Investments in telecommunication clearly show the opposite and larger firms invest per employee twice as much as compared to smaller firms. This indicates that there are scale effects at work for hardware and software investments such that large firms have a scale advantage here. For telecommunication the opposite holds true: large firms have a more complex organizational structure, have more often different establishments, and so on, such that there is a higher demand for telecommunication investments.

From the above the question arises of what determines the diffusion process of adopting e-business practices and can we explain the observed diffusion patterns, so this chapter focuses on the adoption and diffusion of e-business. The questions addressed in this chapter are: a) what is the impact of a new (cost saving or efficiency increasing) technology on market structures? b) what is the relation between market structure and the adoption of new technologies? and finally, c) how can we explain differences in the time of adoption of e-business between smaller and larger firms? To answer these questions, the remainder of this chapter is organized as follows: the next section presents a basic model setup where firms with different technologies operate in a market characterized by monopolistic competition. This results in a market equilibrium where firms differ in cost structure and, consequently, have a different size. Given this basic setup, investment in ICT and e-business practices is discussed and I show that both scale advantages and higher adjustment costs for larger firms can explain different size-dependent motivations to adopt or not to adopt this
new technology. However, the time dimension is not included and it is shown that more is needed to generate diffusion patterns.

For that reason, network effects are introduced and provide an endogenous time dimension, and complete the theoretical model. Finally simulation results show the basic properties of the model and also show the effects of changing market structures on the adoption and diffusion of e-business practices. It is shown that medium-sized firms are the early adopters; the introduction of e-business practices reduces the number of firms in the market (the least productive, smallest firms are driven out); and that increased price competition reduces the number of producers in the market but also reduces the ultimate relative diffusion level of e-business practices.

4.2 A SIMPLE MONOPOLISTIC COMPETITION MODEL WITH FIRM-SPECIFIC COSTS

This section sets up the basic model, without investments in ICT, along the lines of Montagna (1995). The framework used is a simple monopolistic competition model where each firm produces one variety of final output and each firm also faces specific marginal costs. This market structure is realistic for many markets and it allows for different firm sizes, a property that is used later on. Differences in marginal costs will lead to different prices and thus to firm-specific final demand and output. So by assuming firm-specific marginal costs – because of differences in employed technologies, management quality, or skills of the employees, and so on – it is possible to model different firm sizes in a monopolistic competitive setting. Later on I introduce the adoption of e-business practices and – as discussed above – one of the factors that influences intra-firm diffusion is the size of the firm. So the basic model will provide such a setting.

The demand side is characterized by a representative consumer with a love of variety utility function:

$$U = \left( \sum_{i=1}^{N} x_i^{(\sigma-1)/\sigma} \right)^{\sigma/(\sigma-1)}$$  \hspace{1cm} (4.1)

where $x_i$ is the consumption of variety $i$, $N$ is the number of varieties, and $\sigma > 1$ is the elasticity of substitution between varieties. The representative consumer maximizes its utility subject to the budget constraint

$$P \cdot Y = \sum_{i=1}^{N} p_i \cdot x_i$$  \hspace{1cm} (4.2)
where $p_i$ is the price of good $i$ and $P \cdot Y$ is total available income. The aggregate price is defined as:

$$P = \left( \frac{1}{N} \sum_{i=1}^{N} p_i^{-\sigma} \right)^{1/(1-\sigma)} \quad (4.3)$$

As in Montagna (1995) I assume that nominal income is equal to $Y = A \cdot P^{-\eta}$ where $A$ is a positive constant and $\eta$ reflects the price elasticity of final demand. Note that I use a partial equilibrium framework where nominal income is not affected by profits and labour income. Maximizing utility subject to the income gives the demand for each variety:

$$x_i = \frac{A}{N} P^{\sigma-\eta} p_i^{-\sigma} \quad (4.4)$$

for all goods $i$. So the demand for an individual good depends on its own price and on the aggregate price. As long as $\sigma > \eta$ – which I assume to be the case – the demand for an individual good depends positively on the aggregate price and negatively on its own price.

Each firm produces one variety and I assume that firms differ in employed technology, so in marginal costs there is a one-to-one relation between varieties and firms. Since the demand for each variety depends on price $p_i$, firms will face different cost structures leading to different prices and output as we will see below. Firms face a cost structure:

$$c_i = \beta_i x_i + F \quad (4.5)$$

Where $\beta_i$ denotes the firm-specific marginal costs and $F$ the fixed per period costs. Although firms face different marginal costs, and will have different market shares, I assume that the fixed costs are firm independent. Note that I also implicitly assume equilibrium in the product market. Maximizing profits subject to the demand function (4.4) yields the familiar pricing function:

$$p_i = \frac{\sigma}{\sigma - 1} \cdot \beta_i \quad (4.6)$$

Such that output for firm $i$ is equal to:

$$x_i = \left( \frac{\sigma}{\sigma - 1} \right)^{-\sigma} \frac{A}{N} P^{\sigma-\eta} \beta_i^{-\sigma} \quad (4.7)$$

So the output per firm is a function of its marginal costs, the aggregate price level and the number of firms in the market. Below I use the basic model to allow for the adoption of new technologies where the size of firms plays
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a crucial role in the decision to adopt or not to adopt a new technology. From (4.7) it is clear that - within this setup - different firm sizes can only be established by assuming different marginal costs. Following Montagna (1995) I assume that differences between firms are reflected by a spread of marginal costs within an interval between $1 - \delta$ and $1 + \delta$ of the average marginal costs: $\bar{\beta}(1 - \delta) \leq \beta_i \leq \bar{\beta}(1 + \delta)$. All existing firms know their marginal costs, whereas entrants will face marginal costs from a random draw from this distribution, which we assume to be uniform. So an entrant faces fixed costs $F$ and unknown marginal costs which are drawn from a uniform distribution. Existing firms know both the fixed and the marginal costs. Profits can be easily derived from (4.5), (4.6), and (4.7):

$$\pi_i = \frac{\phi \cdot A}{N} \cdot \frac{\sigma - \eta}{\gamma} \cdot (\bar{\beta}^{1 - \sigma} - F) \quad (4.8)$$

with $\sigma = \sigma - \eta \cdot (\sigma - 1)^{n-1}$.

Output per firm is determined by (4.7) and total per period profits by (4.8). Finally, entry and exit conditions determine the steady state solution, which depends on the number of firms in the market ($N^{**}$) and the minimum efficiency $\beta^{**}$ that is required to obtain non-negative profits. As long as the expected profits are positive, firms will enter the market. This reduces the profits of all firms and leads to bankruptcy of those with the highest marginal costs, hence the marginal firms drop out. But this drop-out increases the average efficiency of production, and it also reduces the aggregate price level and increases aggregate demand, thereby attracting new entrants. In the steady state, the entry and exit dynamics will come to an end and for any number of firms in the market there is a minimum efficiency for which the expected profits are zero. For a given number $N^*$ the entry condition is:

$$V^E = \int_{\beta_{(1-\delta)}}^{\beta_{(1+\delta)}} \Pi(\beta, N^*) \cdot f(\beta) d\beta \geq 0 \quad (4.9)$$

where $V^E$ is the expected profit of the potential entrant, $\Pi(\beta, N^*)$ is the profit function (4.8) and $f(\beta) = 1/(2\bar{\beta})$ is the density function of the random distribution. So as long as $V^E$ is positive, firms will enter the market and will affect existing firms as described above. Firms will stay in the market as long as their profits do not become negative, that is, as long as $\Pi(\beta^{**}, N^{**}) \geq 0$. This continues until this term equals zero. Solving for $V^E(N^{**}) = 0$ and $\Pi(\beta^{**}, N^{**}) = 0$ gives the number of firms in steady state:

$$N^{**} = \frac{1}{2\delta} \cdot \frac{\phi \cdot A}{F} \cdot \frac{\sigma - \eta}{\gamma} \cdot \bar{\beta}^{1 - \sigma} \cdot \frac{1}{2 - \sigma} \cdot \frac{1}{(\bar{\beta} + \delta)^{2 - \sigma} - (1 - \delta)^{2 - \sigma}} \quad (4.10)$$
and the efficiency cut-off point:

\[
\beta^{**} = \beta \left( \frac{1}{2\delta - 2 - \sigma} \left( (1 + \delta)^{2-\sigma} - (1 - \delta)^{2-\sigma} \right) \right)^{-\frac{1}{\sigma}}
\]  

(4.11)

which is the same as in Montagna (1995) except for the average efficiency term \( \bar{\beta} \). The characteristics of the steady state with fixed average marginal costs are extensively described in Montagna (1995). The next section introduces a new technology that reduces the marginal costs of those who adopt that technology. Here we concentrate on the effect of an overall decrease of marginal costs. From (4.11) it is clear that a decrease of the average marginal costs (a reduction in \( \bar{\beta} \)) will proportionally decrease the minimum entry point \( \beta^{**} \). The effect of an overall increase in efficiency on the number of firms (and thus varieties) includes a direct effect, but also an indirect effect through changes in the aggregate price level and thus changes in aggregate demand. In the steady state the aggregate price level is given by:

\[
P = \left( \frac{1}{N^{**}} \int_{\beta^{**}}^{\bar{\beta}^{**}} \frac{N^{**}}{\beta^{**} - \beta(1 - \delta)} P(\beta)^{1-\sigma} d\beta \right)^{\frac{1}{1-\sigma}}
\]

\[
= \frac{\sigma}{\sigma - 1} \left( \frac{\beta^{**^{1-\sigma}} - \left[ \beta(1 - \delta) \right]^{2-\sigma}}{(2 - \sigma)(\beta^{**} - \beta(1 - \delta))} \right)^{\frac{1}{1-\sigma}}
\]  

(4.12)

The effect of an overall change in the marginal costs \( \bar{\beta} \) on the number of active firms in the steady state depends on the elasticity of substitution between products as well as on the aggregate price elasticity. From (4.10) it follows that the number of firms depends negatively on the average marginal costs. This is the direct effect at firm level only, however. Since an overall change in the marginal costs also affects the aggregate price level—through changes in \( \beta^{**} \) and of course through \( \bar{\beta} \) itself in (4.12)—total final demand also changes and the final effect on the number of firms that remain in the market depends on \( \sigma \) and \( \eta \).

Figure 4.1 displays \( dN^{**}/d\bar{\beta} \) for various values of both elasticities. For \( \eta > 1 \) (an elastic output market) a decrease in the marginal costs will decrease the price of each individual good (see equation (4.6)), thereby decreasing the aggregate price level, which in turn has a more than proportional demand effect (due to \( \eta > 1 \)), which attracts new firms, so \( dN^{**}/d\bar{\beta} \) is negative if \( \eta > 1 \). The opposite is true for \( \eta < 1 \) and for \( \eta = 1 \) there is no effect of a change in the average marginal costs on the number of firms. The latter can be easily detected from (4.10) since the change in the aggregate
price level is equal to the change in the marginal costs and with $\eta = 1$ the effects cancel out each other in the number of active firms in steady state.

The analysis so far is restricted to the case in which all firms adopt a new technology, and does not allow for diffusion of new technologies. Firms differ from each other with respect to the marginal costs, but the technology is drawn from a uniform distribution and firms do not choose the employed technology. The effect of an overall increase in efficiency, that is by decreasing the average marginal costs, and the effect on the number of firms crucially depends on the aggregate price elasticity as well as on the elasticity of substitution between varieties. Based on this basic setup, the next section allows for the adoption of e-business practices and firms will choose to adopt or not to adopt these practices, mainly depending on the investment costs as well as on the adjustment costs needed to reap the benefits of ICT investments. Medium-sized firms are likely to be the early adopters. The time dimension is introduced afterwards, however.

4.3 ADOPTING E-BUSINESS

It is obvious that not all firms use the Internet for their transactions, communication, and marketing from the outset and even if firms moved to the
Internet, they did not all do it to the full extent immediately. So we face inter- as well as intra-firm diffusion processes of new technologies. Although we find many different explanations for delayed adoption of new technologies in the literature, most of them can be explained using a threshold model. The basic assumption is that firms differ from each other with respect to one or more characteristics that are important for investment decisions. A reason for not adopting a new technology can be the magnitude of adjustment cost. If investment in a new technology involves a cost of adjustment that depends on firm size, small firms, with a low adjustment cost, may adopt new, but costly, technology, whereas larger firms, with a relatively higher adjustment cost, may rationally decide not to adopt. A diffusion process can be explained if either the threshold moves, for example because of decreased investment cost or increased profits, or if the distribution moves, for example because of decreasing adjustment costs. So a typical characteristic of these probit models is that moving either the threshold or the distribution, or both generates a diffusion curve. The forces behind these movements are either exogenous or endogenous. This section focuses on the gains and costs of adopting a new technology – e-business practices – whereas the next section introduces the time dimension that generates diffusion patterns.

For the model developed in this section we start from the basic setup as described above, where firms differ in size (because of different initial technologies) and adoption costs of Internet technologies (or ICT in general) are related to firm size. Investing in the Internet involves an adjustment cost because the entire internal (administrative) structure of firms has to be adjusted for a successful transformation towards Internet-based commerce. This implies that for instance larger firms may experience a relatively larger adjustment cost than smaller firms do, just because of their more complex internal structure, which is consistent with the findings of Hollenstein (2002). On the other hand, larger firms may benefit from economies of scale of training and implementing new systems, whereas small firms may face indivisibilities of for instance hiring specialized ICT personnel.

So as well as the direct investment costs of IT hardware and software, firms face other costs and obstacles that have to be taken into account. Moreover, such additional adjustment costs are larger than the capital investments in many cases, as reported for example, Brynjolfsson and Hitt (1996), and Bresnahan et al. (2002). There is also evidence that reorganization of the workplace is necessary in order to reap the gains from ICT investments; see for example, Arvanitis (2004), Bertschek and Kaiser (2004) and Borghans and ter Weel (2004). In a survey-based study, Hollenstein (2004) also finds such a relation but in addition he finds evidence that the lack of know-how is an obstacle for the successful adoption
of the Internet and Internet-based commerce. Moreover, firm size is shown to be a significant determinant in such adoption processes. Because of their complexity, large firms face higher reorganization costs and need more high-qualified personnel to successfully implement new technologies.

On the other hand, small firms – and especially micro firms with fewer than 10 employees – face the problem of finding financial resources to invest in ICT and also face indivisibilities with respect to (qualified) ICT personnel. The latter implies that small firms face higher costs or larger obstacles to invest in ICT. So firms face two different costs: the reorganization costs on one hand and investment costs on the other. The latter include learning/training, setting up new systems, converting databases, and so on, and are very likely to increase with firm size, but less than proportionally because of positive scale effects. As noted above, reorganization costs are likely to increase more than proportionally with firm size as complexity increases. It should be noted that successful implementation of ICT in business is not limited to setting up and maintaining a corporate website or using email for all employees. Successful use of ICT implies connection of internal information systems with similar systems of suppliers and customers such that logistic processes are automated and optimized. Moreover, in many cases purchasing intermediate goods can be done via electronic auction marketplaces such that prices will drop, inventories can be decreased and overall efficiency increases.

The above implies that the investment costs can be written as a function of firm size. More specifically, both the reorganization costs and the additional investment costs are a function of output. Concerning investment costs we assume:

\[
ir(x) = e_0 + e_1 \cdot x^\varepsilon \quad \text{where } e_0, e_1 > 0 \text{ and } 0 < \varepsilon < 1
\]  

(4.13)

So the investment costs are equal to \(e_0\) for firm size equal to zero and are increasing, but at a diminishing rate with respect to firm size. Reorganization costs are represented by a similar function:

\[
r(x) = \lambda_0 \cdot x^\lambda \quad \text{where } \lambda_0 > 0 \text{ and } \lambda > 1
\]  

(4.14)

which is also increasing but at a faster rate because of the greater complexity of larger firms. So total investment costs are equal to the direct investment costs plus the two additional cost components:

\[
i(x) = ir(x) + r(x)
\]  

(4.15)

The benefits from investing in e-business technologies are modelled by a reduction in marginal costs. Here I assume that marginal costs decrease by
a percentage $\Delta$ for those who invest in e-business, so $\beta^o = \beta^n \cdot (1 - \Delta)$ where superscripts $o$ and $n$ denote old (pre-investment) and new (post-investment) situations, respectively. Note that we do not include intra-firm diffusion in the model; it is simply assumed that firms either invest in e-business or not, but if they invest, they do it to the same (full) extent. From (4.8) this implies that the gross (expected) profits increase by:

$$\Delta \pi_i = \left( \frac{\psi \cdot A}{N} p^o - \eta \right) \cdot \beta_i^{d - \sigma} \cdot (1 - \Delta)^{1 - \sigma - 1}$$  \hspace{1cm} (4.16)$$

where I assume that firms disregard the influence of their own investment decision on the aggregate price level and on the number of firms in the industry, as is done above in the basic setup. Investigating the relation between increased profits resulting from investing in the new technology and firm size, that is, rewriting equation (4.16) in terms of the output of each firm, we arrive at:

$$\Delta \pi(x) = \varphi \left( \frac{\sigma - 1}{\sigma} \right)^{1 - \sigma} \left( \frac{A}{N} p^o - \eta \right)^{\frac{1}{\sigma}} \cdot (1 - \Delta)^{1 - \sigma - 1} \cdot x^{\frac{\sigma - 1}{\sigma}}$$  \hspace{1cm} (4.17)$$

which is positive for any output $x$. Inspection of the first and second derivatives with respect to output shows that the first derivative is positive and the second derivative is negative. So the gains from investing in a new technology are positive (as expected), and are larger the larger the firm is but at a less than proportional rate, so additional profits per unit of output decrease with firm size. The concavity of this relation depends on the elasticity of substitution between different varieties, and for large values of this elasticity the relation becomes nearly linear. Estimates of this elasticity show values of 6–12 (Broda and Weinstein, 2004), depending on the level of detail in the classification employed. (Broda and Weinstein, 2004 found an elasticity of 12 in the case of an 8-digit classification and 6 for a 3-digit classification). Similar results were found earlier by Gasior & et al. (1991). An elasticity of substitution of 6 corresponds to a profit margin of 20 per cent and a value of 12 reduces the margin to 9 per cent, which seem reasonable values. The relation between firm size and increased profits because of investment in new technology is rather concave for small values of the elasticity of substitution but becomes nearly linear for larger, and more reasonable, values of this elasticity.

Considering the costs of investing in e-business it is obvious that the above-mentioned gains imply increased profit flows in the future, so these future net gains have to be discounted. However, assuming that firms do not expect other firms to invest in e-business too and that their own
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decision does not affect the aggregate price level and aggregate demand — an assumption that is consistent with the monopolistic competitive market setting — firms will invest in e-business if the investment costs are smaller than the gains, so if:

\[ i(x_i) \leq \int_0^{t_i} \Delta \pi_i \cdot e^{-rt} dt = \frac{1}{r} \cdot (1 - e^{-rt_i}) \cdot \Delta \pi_i \quad \text{so if} \quad r' \cdot i(x_i) \leq \Delta \pi_i \quad (4.18) \]

where \( r' \) is implicitly defined in (4.18). Note that firms do not differ from each other with respect to the planning horizon, so this term is equal for all firms.

Confronting these costs with the gains from investing in e-business technologies and using reasonable values of the elasticity of substitution between different varieties of final goods determines which firms will invest in that technology and which firms will rationally decide not to adopt the technology. A typical example is given in Figure 4.2 where I assume that the gains from investing in e-business increase over time, for the moment due to an exogenous process. The costs are depicted by the convex curve \((ic(x))\) and the discounted gains by the concave curves, for the moment at three different points in time, at \( t_0, t_1 \) and \( t_2 \). At \( t_0 \), no firm will adopt the new technology because the costs exceed the discounted gains. At \( t_1 \), the gains have increased and firms with size within the interval \( x_{1.0} \) to \( x_{1.1} \) will invest, whereas smaller and larger firms do not. If the gains from the new technology increase further, more and more firms will invest in it. Ultimately,

![Figure 4.2 Profits and costs of investing in e-business practices](image-url)
all firms will have invested in e-business, except for the very small ones for which the scale is too small so the gains do not exceed the (fixed) investment costs ($e_0$). It is obvious that this process depends on the parameters of the model, and in particular on the cost structure. If workplace reorganization does not matter, the cost curve becomes concave as a result of the scale benefits of investing in and using Internet technologies, and in such a situation large firms will start to invest first in the new technology and smaller firms are the laggards. For very high reorganization costs, the cost curve becomes highly convex and typically the medium-sized firms will invest in the new technology first. Both the larger and smaller firms are now the laggards. Confronting this with the empirical findings as discussed above, where indeed the medium-sized firms are the early adopters, this implies that reorganization costs matter so the cost curve becomes convex. Moreover, if the gains and costs functions as depicted in Figure 4.2 reflect reality, there is a faster diffusion of the new technology among larger firms relative to small firms. Moreover, the very small (micro) firms will not invest in e-business because of the initial fixed costs, which are not covered by the increased profits.

To finalize the model, the diffusion process should be endogenized and either the costs structure or the discounted gains from investing in e-business processes should change over time. The next section shows that network externalities can be the driving force for such a process. After that some simulation experiments show the properties of the model.

4.4 INTRODUCING NETWORK EFFECTS: FROM EDI TO E-BUSINESS

Above we assumed constant marginal production costs for both the users and the non-users of Internet technologies, but it is questionable whether this is a realistic assumption. Taking a closer look at the way firms use the Internet for their business-to-business commerce, we expect that in the first phase, only a few firms used this technology and that the gains were not that significant. For instance because firms had to use dual communication systems, in the broadest sense of the word, for the simple reason that some of their contacts used the Internet and others not. Moreover, in the early days there was no or only poor integration of Internet-enabled software with, for instance, ERP systems. Even today many large firms still use non-Internet communication technologies to transfer standardized messages (see e.g. Clayton et al., 2004). If more firms move to the Internet, the efficiency gains will increase as a result of a more efficient and integrated approach, because of increased competition on the market for intermediate
goods and cheaper and better (integrated) software packages. This means that the efficiency gains of using the Internet will increase if more firms move to it. That is, the efficiency gains of using the Internet for business-to-business commerce can be characterized by network externalities, which means it becomes more efficient for every user if more firms move to Internet-based e-business practices. Although I do not specify the exact underlying process very precisely, I assume that the efficiency gains are an increasing function of the number of e-business users.

In this respect, a comparison with Internet technologies and the longer existing concepts of Electronic Data Interchange (EDI) is useful. EDI is based on standards concerning the exchange of data in the sense that the format of the business documents to be exchanged is standardized. Although the idea of standardization of these messages is useful, the EDI concept has some drawbacks, one of which is the enormous amount of different standards. Almost every industry has its own standards, so to do business with many different industries, for instance for the purchase of intermediate goods, a firm has to implement all these different standards. The second drawback is that the EDI concept is limited to the format of the documents to be exchanged, that is, it is limited to the format of the messages. The way firms exchange information, that is, the formats firms use to exchange the messages, is not standardized in the EDI concept. This is exactly the point where the Internet comes into the picture. On the Internet, the messages as such are not standardized but the way information is transferred is laid down in open protocols. Currently both protocols are to be integrated through a new Internet standard XML that allows for standardized messaging via the Internet. This process of standardization increases the number of applications and, even more important, increases the compatibility between various systems.

This implies that the efficiency gains of using the Internet for business-to-business commerce can be characterized by network effects, hence it becomes more efficient for every user if more firms move to the Internet. This means that the marginal cost of the users decrease with the number of users. Next to this, it is only natural to expect that there is some upper limit of these efficiency gains so the second derivative of the marginal cost with respect to the number of users is positive and becomes zero, so the marginal costs reach some lower limit asymptotically. Hence, the decrease of marginal cost is rather large at the beginning of the diffusion process but becomes smaller and smaller as the number of users increases. To be more precise, I assume that:

$$
\beta^* = \beta^*_i (1 - \Delta(m)) = \beta^*_i \frac{1 - \Delta_0}{\gamma + (1 - \gamma) \cdot \alpha^m}$$

$$0 \leq \alpha \leq 1, \gamma > 1, \Delta_0 > 0, \Delta(m)' > 0, \Delta(m)'' < 0 \quad (4.19)$$
where $\beta_i^*$ denotes the marginal costs of firm $i$ that introduced e-business, based on its original cost structure $\beta_i^*$ and the reduction $1 - \Delta(m)$ in marginal production costs for a firm using ICT, given that $m$ other firms also adopted the new technology; $\alpha$ controls the speed at which the marginal cost declines and $\gamma$ determines the level of the asymptote. If the number of users is zero, the marginal costs are equal to $1 - \Delta_0$ times the original marginal costs, whereas for a large (infinite) number of users the reduction in marginal cost becomes $(1 - \Delta_0)\gamma$.

A crucial aspect at this point is the treatment of expectations of firms regarding the network effects. As will become clear below, the model becomes very complicated if firms take the adoption decisions of other firms and the future gains resulting from network effects into account when making their own investment decision. Moreover, these effects depend on the firms' characteristics concerning the gains and costs of investments in e-business and in order to be able to take these effects into account, all firms should have knowledge about these characteristics of all other firms. This is a very strong assumption indeed. Therefore the expected marginal cost reduction of a user in period $t$ is equal to $[1 - \Delta(m_{t-1})]$. The (expected) marginal cost of the non-users remains the same as before at $\beta_i^*$. So the model now includes an endogenous force that increases the gains of adopting e-business practices if more and more other firms adopt it too. However, adoption of a more efficient technology also implies changes in the market structure and changes in the incentives to adopt the technology. The result of these different forces cannot be traced analytically and the model characteristics are presented through simulation results.

### 4.4.1 An Example

This section illustrates the working of the model by presenting simulation results. I start from a steady state situation where 250 firms ($N^*$) are active in the market. At a certain point in time a new technology becomes available and some firms will invest in the new technology in this period. In their decision process, firms do not take network effects into account — they are treated as externalities — but they will appear after this initial investment. This increases the gains from adopting e-business practices and also increases the potential gains for non-users, which attracts some other firms to invest in e-business too, thereby increasing the network effects for all users. Moreover, because the marginal costs of the users of e-business will drop, their output price will also decrease and their market share will increase at the expense of the non-adopters. Some non-adopting firms will then face negative profit and will disappear from the market. Above I showed that the number of firms remains the same if the marginal costs of all firms decrease
if $\eta = 1$. Moreover, the efficiency cut-off point $\beta^{**}$ was reduced by the same amount as the reduction of marginal costs of all firms. This result was obtained by moving from the initial to the new steady state, whereas the intertemporal dynamics include the bankruptcy of marginal firms on one hand but also the entry of new firms on the other because of the decreased marginal costs. Figure 4.3 shows that the number of active firms decreases if we do not allow for new entrants, and the introduction of new technology will drive out the marginal firms and create opportunities for new firms. This is in line with Schumpeter's theory of creative destruction. The crucial question in this dynamic process is how the entry costs of entrants relate to the reorganization costs of existing firms. In the basic setup firms do not face entry barriers, so starting a new firm does not differ from continuing an existing one, except for the marginal cost structure, which is uncertain for an entrant and known by an existing firm. Continuing along this line of reasoning, organization costs are zero whereas reorganization costs clearly are not. If that were the case, new entrants would not only fill up the gap that occurs due to bankruptcy of the marginal firms, they would also threaten the position of others due to their relative cost advantage so driving even more existing firms out of the market. The other extreme is that entrants face a similar cost structure as compared to existing firms, so they bear the same investment and adjustment costs if they invest in e-business, even when setting up a new firm, and in that case the number of new firms is equal to the number of firms that went bankrupt.

Here entry is ruled out (except in obtaining the initial steady state) and the aggregate price level falls as more firms adopt the new business
practices and as marginal costs fall. Consequently, total aggregate demand will increase. As more firms use the new technology, network effects increase the profits for all users as well as the expected profits for non-users, and some will also invest in the new technology. In the first stage, the number of users increases exponentially whereas due to the combination of decreased market power and ceasing network effects, the number of adopters decreases at the end of this process. The entire process creates a diffusion curve as depicted in Figure 4.3 and in this particular simulation, some firms – those that survive – will face too high investment costs and will rationally decide not to invest in the new technology. Note that indeed the total number of firms in the market falls over time.

The profits are given in Figure 4.4 for an early adopter and in Figure 4.5 for a non-adopter that stays in the market. Indeed, the profits of non-users decrease as more firms invest in e-business practices and produce at lower marginal cost and thus sell more products. The profits of the users even increase at the beginning of the diffusion process: the gains due to the network effects exceed the decreasing market power. However, as the network effects become smaller and smaller, the decreasing market power becomes more important as a result of which the profits of the users will decline. However, even in that phase of the diffusion process, the decrease in the profits in the non-users exceeds the decrease of the users such that the difference in profit between users and non-users still increases. This implies that still more and more firms will invest in e-business practices. Finally, the difference becomes too small and the diffusion process stops.
Figure 4.5 Profits of a non-adopter that remains in the market (net profits of the new technology remain below the net profits of the old technology, so do not adopt. The firm still makes positive profits)

The difference in the alternative net profits for a non-adopter decreases but the gap is not closed, so this particular (large) firm does not invest in e-business practices, as depicted in Figure 4.5. In this particular example, all small firms that do not adopt e-business will disappear from the market but some large non-adopting firms still manage to make profits and survive.

Finally, investigating the relation between firm size and time of adoption, Figure 4.6 shows that relatively small firms adopt first (in period 6) and the group of adopters spreads in both directions. Output size in Figure 4.6 refers to the final output, after adoption, and it is clearly shown that the largest firms that adopt e-business practices become larger and leapfrog non-adopting firms in terms of output size.

4.5 MARKET STRUCTURE AND ADOPTION OF NEW TECHNOLOGIES

This last section presents the behaviour of the model in a different market structure. What happens if the elasticity of substitution is higher? On the demand side, an increase of $\sigma$ (viewed in a comparative static way) implies that differences in prices between varieties become more important than differences in qualities. So consumers are more sensitive to price
Figure 4.6 Firm size (after adoption) and time of adopting the new technology

differences and firms experience increased price competition, which decreases both the cut-off point $\beta^{**}$ and the number of active firms in the market $N^{**}$. The least productive firms are driven out and consequently the average productivity increases. An increase of $\sigma$ also decreases the markup margin, so prices of all varieties decrease. The aggregate price level falls because of the increased average productivity and because of the decreased price margins. Aggregate demand consequently increases. For individual varieties, two different effects are at work. First of all we observe a rotation of the demand function where the demand for more expensive varieties fall compared with less expensive varieties. Second, since all prices decrease, aggregate demand increases and there is an outward shift of the demand curve. The result is that demand increases for the cheaper varieties (i.e. those produced by the more productive firm), whereas demand decreases for more expensive products, conditional on a unit aggregate price elasticity ($\eta = 1$) as is the case in the present model simulations. Profits develop in a similar way: highly productive firms increase their profits because the lower profit margins are offset by higher volumes, whereas less productive firms experience a decrease in profits, both compared to the initial value of $\sigma$. The decision to introduce e-business practices is also affected by these changes. For the most productive firms, the introduction of e-business yields higher gross profit gains as compared to the original market structure. For the least productive firms the opposite holds true. However, most productive firms also become bigger, so adjustment costs are higher. Given the values of the
parameters, and in particular the value of $\lambda$ ($= 1.8$) in equation (4.14), the increase in adjustment costs outweighs the increase in net profit gains for the largest firms, so they will adopt e-business practices at a later stage or even not adopt at all. This effect is displayed in Figure 4.7, which shows the net difference in profits firms expect to achieve by the introduction of e-business practices at the beginning of the diffusion process. The profitable region in terms of marginal costs is initially between 0.2 (which is equal to $\beta(1 - \delta)$) and about 0.4, the value of $\beta^{**}$. Firms with marginal costs of 0.3 experience a positive net difference in profits when they adopt e-business practices, and they will adopt these practices first while both more and less productive firms will delay adoption. An upward shift of the elasticity of substitution reduces the upper boundary of the profitable region ($\beta^{**}$ is reduced to about 0.35) but also reduces the net differences in profits for both the most productive and less productive firms, that is, the larger and smaller firms. For medium productive, medium sized firms the net difference in profits increases to the extent that more firms will adopt the technology at the beginning of the diffusion process. Hence an increase in the elasticity of substitution between varieties increases competition and the market becomes more concentrated. Fewer firms survive in the steady state. The largest and smallest firms will delay or even suspend adoption whereas medium sized firms will adopt earlier. This is depicted in Figure 4.8: e-business technologies are introduced in period 6 and more firms than before invest in it immediately. This continues to be the case for some years and after that the speed of diffusion slows down.
So even though network effects are stronger in the first instance (since more firms invest in the new technology), the direct gains and costs as described above remain important.

Taken together, this implies that an increase in the elasticity of substitution first of all decreases the number of active firms in the market, while larger firms, given their marginal costs structure, become bigger and smaller firms become smaller. The adoption decision is affected in two ways and includes a shift in both costs and gains. Large firms experience higher profit gains from adopting e-business practices but also face higher adjustment costs. Small firms experience decreasing adjustment costs but even more decreasing profit gains. In both cases these firms will postpone, or even cancel, adoption. For medium-sized firms the shift in gains outweighs the shift in costs, so they will adopt earlier. Comparing the diffusion processes in both cases, the number of adopters increases in the first stage but also slows down faster. In the end fewer firms will adopt the new technology, both in absolute terms and in relative terms. At first sight this may be a counter-intuitive effect since increased price competition would increase the need for new, more efficient, technologies. However, the size of firms is also affected (large firms become larger and small firms become smaller) and adjustment costs and scale effects have an impact on the decision to invest in new technologies.
4.6 CONCLUDING REMARKS

To summarize, this chapter presents the diffusion of e-business practices as an endogenous process where network externalities, firm size and changing market structures are the main determinants. The dynamics of this system imply that in the initial phase of the diffusion process, the profits of adopters increase and non-adopters face a declining market share and declining profits. This is caused by monopolistic price setting behaviour. Because of network effects the gains from adopting e-business practices increase and more firms invest in these practices, competitive pressure increases even more among both the users and the non-users and implies decreasing profits for all, except for those who adopt the new technology. Some firms do not survive this process and, depending on the elasticity of final demand, new entry will occur.

The continued diffusion of e-business practices decreases marginal costs and also decreases the aggregate price level, thereby increasing aggregate demand. In simulation examples the final rate of diffusion is below 100 per cent and in the new steady state the market returns to a situation with reshuffled profits. Reorganization costs reduce the probability that large firms will adopt new work practices, and typically medium-sized firms are the most successful in incorporating these practices, one of the observed notions. Whether large firms will eventually adopt is not determined by the theoretical model and is a matter of parameter values.

Finally, increased price competition through an increased elasticity of substitution decreases the total number of firms in the initial (pre e-business) era. Compared to a market with a lower elasticity of substitution, profits of the largest firms increase and profits of smaller firms decrease. This alsoreshuffles incentives to invest in e-business practices. The speed of diffusion increases in the first instance but, because of adjustment costs and changing market structures, fewer firms, both in absolute and in relative terms, eventually adopt the new technology. Increased (price) competition leads to fewer firms in the market and larger aggregate output. The spread of e-business practices is hampered, however.

From a policy point of view the model shows that further promotion of open standards is beneficial to achieve high adoption rates of e-business practices, that is, increased ICT investment and increased benefits from this investment. It also shows that small firms drop out of the market due to indivisibilities, lack of knowledge, and so on. Special programmes focused on these firms, where skills and knowledge can be shared more easily, could overcome this problem. Finally, adjustment costs of large firms are the last main driver of the diffusion process and increased flexibility of the labour
market could reduce such costs and thereby foster e-business practices among firms.

NOTES

3. See e.g. Helpman and Krugman (1989), Chapter 7, for a similar approach.
4. Although introducing firm-specific fixed costs (larger firms experience larger fixed costs) will lead to a different outcome in quantitative sense, it will (in general) not lead to different qualitative results. Introducing firm-specific fixed costs complicates the model results considerably, however.
5. Note that Montagna (1995) assumes that the average efficiency is equal to unity. Since we allow for new technologies, this assumption is not appropriate in our case, but it does not alter the model in a qualitative sense.
6. Note that the solution is given for $0 < \beta < 1$, $\alpha > 1$ and $\alpha \neq 2$.
7. The literature on adoption and diffusion can be divided into epidemic diffusion models, rational adoption models, and strategic adoption models, see e.g. Thirlle and Ruttan (1987) and Reingenanum (1989).
8. An exception is the game theoretic explanations where changing market structures take care of a changing environment such that identical firms in the absence of risk and uncertainty make different choices; see e.g. Reingenanum (1989).
9. In their industry-based classification they report variety demand elasticities varying between 6 and 8 for paper & printing, chemical products, and office machinery & precision instruments and 20 and above for metalliferous products, transport, food products, and textiles, clothing & leather (Gasiorek et al., 1991, p. 15).
10. Note that values of $\alpha$ between 1 and 2, as used by Montagna (1995), result in profit margins of above 100%, which seems unreasonable.
11. Some efforts have been made, especially by the UN, to come to an international standard across all sectors of industry called EDIFACT (EDI for Administration, Commerce & Transport) but not all companies have embraced this.
12. For a two-period adoption model with perfect foresight, see for instance Katz and Shapiro (1985). Two periods would be far too small to make our point in this chapter and are ruled out.
13. In this simulation, $\delta$ (the distribution parameter of marginal costs) is set to 0.8, the variety elasticity ($\sigma$) is 6, and the price elasticity of aggregate demand ($\eta$) is set to 1. The average marginal costs ($\bar{c}$) are equal to 1, fixed investment costs ($f$) are 0.5, whereas the number of potential firms ($N$) is 2000. The scale parameter ($A$) is adjusted to 5579.5 so that the number of firms in the 'profitable' interval ranging from $(1-\delta)\beta$ to $\beta^{**}$ corresponds to the theoretical value, thereby allowing the density of firms within this interval to be fixed, which is needed within the simulation module. The initial gains from investing in e-business ($A_{0}$ in equation (4.19) are set to 0.02, $\alpha$ is set to 0.9999 and $\gamma$ to 1.2. Finally, in the cost structure of investing in e-business, $e$ is set to 0.5, $e_{2}$ to 0.05, $\lambda_{1}$ to 1.8 and $\lambda_{2}$ to 0.05. Given these parameters, the theoretical value of $A^{**}$ according to equation (4.10) is 250.015 in the initial steady state, which is equal to the simulation results.
14. The difference between gross and net profits is determined by the total investment costs of adopting e-business.
15. As explained, because of network effects the curve will shift upwards, so more firms experience positive gains from adopting the technology at a later stage of the diffusion process.
REFERENCES


