Economies of scale in ICT: how to balance infrastructure and applications for economies of scale in ICT and business
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4 METHOD AND DATA

4.1 Introduction

In this chapter we present our empirical data sets. After that, we will deal with the measurement of the constructs. An additional proxy P2a will be defined, based on the way of measurement of the number of ICT assets. Then the research methodology is explained. The productivity is determined in two ways: the absolute productivity (= scale ICT assets / ICT expenditure) and the relative productivity using Data Envelopment Analysis (Charnes et al 1978).

4.2 Empirical data sets

Since 2002, consultancy firm M&I/Partners has carried out a yearly investigation to review the costs and maturity of ICT in Housing Corporations (Eekeren et al 2006), as explained in section 1.4.1. and Table 1.1. The results of the 2005 investigation are represented as costs per workstation in Figure 4.1. For secrecy reasons the 35 organizations were sorted by size in four groups: small (1-6), medium (7-17), large (18-27), and very large (28-35). The total ICT costs per workstation are made up of two categories: Infrastructure and Applications. Each cost category includes the relevant hardware, software, and personnel costs. The source data were collected using a cost model containing clear definitions of the above-mentioned ICT objects. The source data were validated in communication with the employees responsible for their management. In appendix 1 the cost model of M&I/Partners is defined in more detail.
A similar investigation has been held to review the costs and maturity of ICT in Municipalities and in Hospitals, see section 1.4.1. and Table 1.1. The collection of the ICT data gathered from the Municipalities and the Hospitals took place in a similar way as described above. Appendix 1 contains a more detailed description of the investigation. We will now proceed with the measurement of the constructs defined.

4.3 Measurement of constructs

In this section the variables of the empirical dataset will be used to determine the measurement variables of the defined constructs.

4.3.1 Measurement of ICT expenditure

The TCO model used by M&I/Partners, based on Maanen and Berghout (2001), gives insight into the yearly ICT expenditure of an organization. The ICT expenditure was measured by the total ICT costs of the organization. In Figure 4.2 this is represented as Total ICT cost = a+b+c+d+e+f. Because of the availability of the data, we will use the number of ICT Full Time Equivalents (FTE) instead of the costs of ICT personnel for operations and maintenance in the remainder of this thesis. Infrastructure HW/SW costs are determined by costs for workstations, peripherals, servers and storage, communications and facilities, plus the infrastructure software costs. Applications SW cost concern software licences and services, including interfaces between applications. For more details see Appendix 1. Note that infrastructure software (server operating systems and middleware) is included in “Applications” instead of “Infrastructure” in the cost model of M&I/Partners. This is based on a different definition of “Infrastructure” as collection hardware components instead of a collection services including the integrative software. The advantage of the M&I definition is that the infrastructure is solely based on hardware, corresponding with the “law of Moore”, as explained in section 2.7. The disadvantage of the M&I definition is that infrastructure software is not included, that is responsible for the increase of the productivity of the ICT management. However, it happens very often that an organization purchases productivity increasing infrastructure management software, which is not effectively implemented in the organization. The reason is that the processes in the ICT organization have to be changed, which is in general very time consuming: after years of effort the ICT organization benefits from these investments. Concluding, we consider the M&I definition better at this level of data granularity. Only if more detailed data is available about the costs of these organizational changes, then it is worthwhile to measure the infrastructural software.
### Two divisions of Total ICT cost

<table>
<thead>
<tr>
<th></th>
<th>TIR cost (HW/SW)</th>
<th>HIR (cost) operations</th>
<th>HIR cost innovation</th>
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</thead>
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<tr>
<td>Infrastructure cost</td>
<td>a</td>
<td>b</td>
<td>c</td>
</tr>
<tr>
<td>Applications cost</td>
<td>d</td>
<td>e</td>
<td>f</td>
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</tbody>
</table>

Total IT cost = a+b+c+d+e+f

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**Figure 4.2 Divisions of ICT cost**

#### 4.3.2 Measurement of the scale of the ICT assets

In the translation of the scale of ICT assets to ICT expenditure an intermediate variable is used, the complexity of ICT assets, as explained in section 3.4. As described there are two ways to determine the effort of ICT labour (= complexity ICT assets) to manage ICT assets, based on the definition of Backlund (2002). In the first way the *number* of ICT assets (including relations and types) is used to determine the scale of ICT assets; in the second way the *cost* of ICT assets are the point of departure to determine the scale of ICT assets. As indicated in the research model (Figure 3.10) these two views on measurement (number of ICT assets and costs of HW/SW) of the scale of ICT assets lead to the determination of the FTE Operations as measurement of ICT expenditure. First the “ontological” or number view will be elaborated and afterwards the “descriptive” or cost view.

**“Ontological” or number view**

As stated above, the scale of the ICT assets is in the “ontological” view defined by the scale of the applications, the scale of the infrastructure, and the scale of the users, see Figure 3.5. When comparing the scale of the ICT assets of two organizations of the same type (for example Housing Corporations), the following can be observed.

- The scale of the *infrastructure* can be determined by establishing the number of different components. The number of workstations appears to be a good estimator of the number of other types of infrastructure components, such as servers and network components.
- The scale of the *users* can be indicated by the number of different users, in general all employees of an organization. However, the number of *workstations* represents the scale of
the active users. In this research we therefore used both the number of FTE and the number of workstations.

The scale of applications will be determined in two ways, (a) and (b):

a) The portfolios of the applications are highly comparable because the Corporations’ business processes and the information requirements are more or less similar. The variety of the applications is determined by the different business processes, which are highly comparable. For example, general ledger, word processing, and e-mail are used by every organization. Therefore the number of application types (variety) is more or less the same for all organizations of a particular benchmark group. This implies that the scale (a) of applications for two organizations with the same number of workstations is more or less the same.

b) One of the dataset’s variables represents the number of application types, in accordance with the relevant business processes, that are supported by these applications. The weighted number of application types is determined by (1) the existence of operational applications and (2) the importance of these applications for the business (see Appendix 1). This implies that the scale (b) of applications for two organizations with the same number of workstations is determined by this weighted number of application types.

In the above (see Figure 3.3) we defined an overall scale variable N representing the scale of the ICT assets. The scale of the ICT assets N was established by two variables:

a) The number of workstations as a representation of the scale of the infrastructure, the scale of the users and the scale (a) of the applications, based on the assumption that the application variety is equal for all organizations of the same type:

\[ \text{Scale ICT assets} = \text{number of workstations} \]

b) A combination of the number of workstations (scale infrastructure), the number of FTE of the organization (scale users) and the scale (b) of the applications, based on the weighted number of application types. Formally defined, according to the distance-based approach a compound measurement is conducted as follows (Poels and Dedene 2000):

\[ \text{Scale ICT assets} = \sqrt{\text{workstations}^2 + \text{FTE}^2 + \text{applications}^2} \]

To make the 3 variables mutually comparable, each variable is divided by the average value of that variable.

NB For the Municipalities and the Hospitals the number of applications is not known, so the scale is determined only by workstations and FTE.

In this research only organizations of the same type will be compared with each other and we think that the number of workstations is the best representation of the scale of ICT assets. We have only a simple count of applications without knowing whether these are simple or complex applications. We have only a simple count of users without knowing whether they are “light” or “heavy” users. Therefore we can define the following corollary on proxy assumption P2:

(P2a) The number of workstations is a better measurement of the (3) scale of ICT assets than the combined scale factor.
“Descriptive” or cost view

Earlier we pointed out that the translation of scale of the ICT assets to the effort of ICT management will in the “descriptive” view be based on the cost of HW/SW. In Figure 4.2 the cost of HW/SW (TIR) are represented as part of Total ICT cost. The TIR cost (a+d) can be related to the HIR cost operations (b+e). This is represented in the research model Figure 3.10 line 3, according to proxy P2.

4.3.3 Measurement of the efficacy of ICT management policies

The measurement of the efficacy of ICT management policies was approached from two different points of view:

a) The technological point of view, in which the investments in the ICT infrastructure are important.

b) The point of view of the maturity of the ICT organization.

Ad a) In this research the investments in ICT infrastructure were measured by the infrastructure part of the total ICT costs. This measure is called the Infrastructure Factor (IF). In terms of Figure 4.2 the following holds: Infrastructure factor = (infrastructure cost)/(total ICT cost) = (a+b+c)/(a+b+c+d+e+f). The infrastructure costs appear to vary from about 30% to 70% of the total ICT costs. We think that an investment in infrastructure will last for more years, so we determine the average IF for the years that precede a certain year, including that year; this measure is called the average IF. If for a certain organization data are available for the years 2002-2007, then the average IF for 2007 is the average of the IF values for the years 2002-2007. However, not all organizations participated in all benchmarks for all years. If for example for some organization data are only available for the years 2005 and 2007, then the average IF for 2007 is the average of the IF values for the years 2005 and 2007. In table 1.1 the number of organizations and the number of years are represented. The median number of years is 2 for Housing Corporations, 3 for Municipalities and 1 for Hospitals. In section 6.3.2 the limitations of the measurement of the average IF are discussed.

Ad b) The maturity of the ICT organization is defined by 17 different aspects, see Figure 4.3, based on COBIT and adjusted by means of the most relevant ITIL operational processes. M&I/Partners have translated these aspects into the specific situations of Housing Corporations, Municipalities and Hospitals. Each aspect can be scored on a scale from 0 (the process is not organized) to 5 (the process is completely optimized). Figure 4.3 represents the average maturity of the Housing Corporations in 2005. The 2004, 2006 and 2007 investigations show almost the same results (for the period 2002-2003 no maturity data were available). This measure is called the Maturity Factor (MF). For the Municipalities the maturity data are available for the period 2005-2007 (for 2004 no maturity data were available). For the Hospitals the maturity data are available for the period 2006-2008.
4.3.4 Measurement of organization performance

For the measurement of organization performance of Housing Corporations, Municipalities and Hospitals, the yearly turnover in € is available in the M&I dataset.

Based on the definitions of the constructs and the empirical data sets we are now able to develop a suitable methodology.

4.4 Methodology

In this research we will perform a global and a detailed analysis concerning the validity of the hypotheses H1-H2 and proxies P1-P3. The global analysis consists of Partial Least Square (PLS) regression and linear regression to obtain a global view regarding the validity of the
hypotheses and proxy assumptions. In the detailed analysis we will determine in detail the validity of the hypotheses and proxies. All analyses are based on least squares:

- In the global view we assume linear relations between the inputs and outputs of the ICT respectively business processes.
- In the detailed view we assume functions of the form \( y = a \cdot x^b \) with \( y \) = output and \( x \) = input of the ICT respectively business processes.

Furthermore, in the global analysis we will analyse the whole dataset over all years, while in the detailed analysis we will perform a Mann Whitney analysis to separate the low and high productivity organizations in every year with statistical significance (\( p<0.05 \)). In the global analysis no statistical significance analysis is performed. We expect that in the global view the degree of validity of hypotheses is higher than in the detailed view, as the requirements in the detailed view are more specific and the analysis is more rigorous. In Figure 4.4 the difference between the global view and detailed view is represented in terms of the degree of statistical significance, depicted on the x-axis.

![Diagram showing the scope of analysis and significance](image)

**Figure 4.4 Scope and significance of global and detailed analysis**

Another aspect is the scope of the analysis: the PLS method is a holistic analysis of the whole field of research, i.e. ICT and business together. Linear regression is concerning ICT and business separately. In Figure 4.4 the scope variable is depicted on the y-axis. The same distinction can be made in the detailed analysis: first we analyse H1 and H2 separately; afterwards H1 and H2 are simultaneously analyzed, as the scope is extended to ICT and business together. In Figure 4.4 an arrow is drawn to indicate the sequence of the four types of analyses, which become more and more rigorous in terms of statistical power (Baroudi and Orlikowski 1989). We try to reach an internal validity as high as possible, in testing our hypotheses by these four types of analysis. See further section 6.3 Limitations.
4.4.1 Global analysis

In the global analysis we will analyse the whole dataset over all years: we first perform PLS regression and afterwards linear regression.

PLS regression is a method to solve a Structural Equation Model (SEM), as explained by Gefen et al (2002). In Figure 4.5 a SEM model of this PhD research is represented, which is derived from the research model in Figure 3.10. Figure 4.5 consists of 4 ellipses, representing the 4 constructs of this Research; the ellipses are connected by arrows representing the dependencies between the constructs. The rectangles represent the variables measuring the constructs.

The ICT expenditure construct is measured by the reflective variables Total ICT cost and FTE Operations. Reflective variables “reflect” the construct and as a representation of the construct should be correlated (Cronbach’s Alpha of Total ICT cost and FTE Operations has the value of 0.94). The arrows in Figure 4.5 go from the construct ICT expenditure to the 2 variables that reflect the construct.

The construct Organization performance is measured by the reflective variable Turnover. The construct Scale of ICT assets is measured by the formative variables Number of ICT assets (Workstations, Applications and FTE Organization as is explained in relation to proxy P2a in section 4.3.2) and Cost TIR (Hardware/Software). Formative variables “cause” the construct i.e., represent different dimensions of it (arrows in Figure 4.5 go from the 4 variables to the construct Scale of ICT assets).

The construct Efficacy of ICT management policies is measured by the formative variables Infrastructure Factor (IF) and Maturity Factor (MF).

As we can see by the arrows in Figure 4.5, the construct ICT expenditure depends on the construct Scale ICT assets and on the construct Efficacy of ICT management policies. The same holds for the construct Organization Performance, that depends on the construct Scale ICT assets and on the construct Efficacy of ICT management policies. These dependencies are determined via an holistic analysis called PLS, minimizing the sum of squares of the differences between modelled values and real values (of the dataset). The difference between PLS and linear regression is that in linear regression the sum of squares of a more limited model is determined. We might say that in the case of Figure 4.5 the PLS model is the sum of two linear regression models: ICT expenditure = f (ICT assets, Efficacy of ICT management policies) and Organization performance = g (ICT assets, Efficacy of ICT management policies), as the sum of all squares is minimized.

NB Some relations in Figure 4.5 are excluded in the research model in Figure 3.10. The following combinations of dependent and independent variables will be excluded:
- The relation between TIR cost and Total ICT cost: in the research model Figure 3.10 we showed that we will not analyze this combination, as TIR cost are a part of Total ICT cost.
- The relation between TIR cost and Turnover: in the research model Figure 3.10 we showed that we will not analyze the influence of Hardware/Software cost on the Turnover.
- The relation between MF and Turnover: in the research model Figure 3.10 we showed that we will not analyze the influence of the maturity of the ICT organization on the Turnover.
4.4.2 Detailed analysis

In the detailed analysis we will analyse the datasets for every year: we first perform a separate analysis of H1 and H2 and afterwards a simultaneous analysis of H1 and H2.

Separate analysis of H1 and H2

The detailed research methodology concerning the validity of the hypothesis H1 is oriented to the determination of the parameters of the functions \( y = a \cdot x^b \) in Figure 3.2, with \( y = \text{ICT expenditure} \) and \( x = \text{scale of ICT assets} \).

This process is executed in two ways: determining absolute productivity (= scale ICT assets / ICT expenditure) and determining relative productivity using Data Envelopment Analysis (which will be explained below).

We developed an analysis process consisting of three steps, see Figure 4.6:
1) For each of the 8 combinations (see Figure 3.10) of the:
   a. ICT management policies criterion, either a) Infrastructure Factor IF average or b) Maturity ICT organization MF,
   b. ICT Expenditure criterion, either a) total ICT costs or b) ICT personnel for operations and maintenance,
   c. ICT assets scale, either a) number ICT assets (measured by Workstations or the Combined scale factor) or b) cost HW/SW,
there were data available of a quantity of \( n_1 \) organizations in year 1, a quantity of \( n_2 \) in year 2, and a quantity of \( n_3 \) in year 3 (etcetera up to and including year 6).

2) For each year (1, 2 or 3) the (absolute or relative) productivity value of each organization was determined. Next, the group of organizations with the highest efficacy of ICT management policies was compared to a group (of the same size) with the lowest efficacy in terms of productivity values (the middle group was excluded). If Mann Whitney \( p < 0.05 \), there is a statistically significant difference between the productivity values of the two groups in a particular year. In year 1, the high (and low) efficacy groups were assumed to consist of \( m_1 \) organizations. The same applied to year 2 (\( m_2 \)) and year 3 (\( m_3 \)).

3) For the total of \( m_1 + m_2 + m_3 \) organizations with high efficacy values in year 1-3, a regression analysis was performed resulting in \( a(\text{high}), b(\text{high}), \text{Rsq (high)} \) in the equation \( y = a \times x^b \) with \( y = \text{ICT expenditure} \) and \( x = \text{scale of ICT assets} \). Also for the total of \( m_1 + m_2 + m_3 \) organizations with low efficacy values in year 1-3 a regression analysis was performed, resulting in \( a(\text{low}), b(\text{low}), \text{Rsq (low)} \).

For each of the 8 combinations of ICT management efficacy criterion, ICT expenditures criterion and ICT assets scale:

1) Data year 1, year 2, year 3

2) Mann-Whitney \( p < 0.05 \)

3) \( a(\text{high}), b(\text{high}), \text{Rsq (high)} \)

\( a(\text{low}), b(\text{low}), \text{Rsq (low)} \)

Figure 4.6 Overview of the analysis processes in steps (1), (2) and (3)

For measuring the relative productivity, Data Envelopment Analysis (DEA) is used (Charnes et al 1978; Banker et al 1984; Banker and Kemerer 1989; Stensrud and Myrteit 2003; Leitner 2006). With this method the productivity of ICT is measured by calculating its relative productivity within a set of comparable organizations. This allows us to benchmark and rank these organizations with respect to their productivity. DEA is an approach to estimate the production function of organizations, enabling the assessment of their productivity. An advantage of this method is that it can cope with variables of different scales.
and that it incorporates multiple input and output ratios. But most of all, through its benchmarking approach, DEA provides a competitive analysis by matching actual practice with reference targets. As a result it reveals the strengths and weaknesses of an organization in relation to its peer organizations. Furthermore, it enables ranking, as the organizations under study are evaluated in a comparative manner.

The DEA model (maximisation of organizations’ productivity by using linear programming) has the following form: Maximise ((sum of weighted outputs) / (sum of weighted inputs)). The higher this ratio, the more productive the organization. So this model evaluates different, independent organizations operating with the same technology. The productivity of each separate organization is measured relative to the other organizations, where the maximum productivity is 1. In general productivity is therefore delineated as follows: 

\[ 0 < \text{productivity} \leq 1 \]

Within the scope of this research productivity is defined as:

- Input: ICT expenditure
- Output: scale ICT assets
- Productivity = output / input (in DEA this quotient is called ‘efficiency’, but in this research the term ‘productivity’ is used).

The DEA frontier software used (Zhu 2003) was parameterised as follows: one input, more outputs, variable returns to scale. For a more detailed description of DEA see Appendix 2.

The research methodology concerning hypothesis H2 is oriented to the determination of the parameters of the functions \( y = a \cdot x^b \) in Figure 3.8, with \( x = \) scale of ICT assets and \( y = \) Organization performance.

The absolute and relative productivity are determined as above described in Figure 4.6, for the following 2 combinations (see Figure 3.10):

a. ICT management policies criterion: measured by IF average.
c. ICT assets scale: number ICT assets: measured by Workstations or the Combined scale factor.

**Simultaneous analysis of H1 and H2**

H1 and H2 will be simultaneously analyzed, as represented in Figure 4.7. In this Figure the ICT conversion process (1) and the Business processes (2) are represented by boxes. In the separate analyses these two processes are considered independently. However, for a reliable determination of the minimum (“Min”) and maximum (“Max”) value of the Infrastructure Factor IF (see Figure 3.7), we have to consider the ICT assets as output 1 equal to the ICT assets as input 2. Indeed, the same organizations that contribute to Graph (1), should contribute to Graph (2) in Figure 4.7. Therefore in the simultaneous analysis we have an additional constraint compared to the separate analysis: organizations that contribute to Graph (1) and that do not contribute to Graph (2), should be left out of the analysis of process (1) and vice versa.
In the preceding sections we have derived the following hypotheses and proxy assumptions:

(H1) When the (1) efficacy of ICT management policies is low, the (2) ICT expenditure is higher than average, given the (3) scale of ICT assets.

(H1’) When the (1) efficacy of ICT management policies is high, the (2) ICT expenditure is lower than average, given the (3) scale of ICT assets.

(P1) The cost of ICT human resources concerning operations and maintenance is a better measure of the (2) ICT expenditure construct than the total ICT cost.

(P2) The number of ICT assets is a better measure of the (3) scale of ICT assets than the cost of hardware/software.

(P2a) The number of workstations is a better measurement of the (3) scale of ICT assets than the combined scale factor.

(P3) Investment in ICT infrastructure is a better measure of the (1) efficacy of ICT management policies construct than the maturity level of the ICT organization.

(H2) When the (1) efficacy of ICT management policies measured by the Infrastructure Factor (IF) is low, the (4) Organization performance is higher than average, given the (3) scale of ICT assets.

(H2’) When the (1) efficacy of ICT management policies measured by the Infrastructure Factor (IF) is high, the (4) Organization performance is lower than average, given the (3) scale of ICT assets.
We used the following ways of measurement of the four constructs:

1. Efficacy of ICT management policies: a) average Infrastructure Factor (IF) and b) Maturity Factor (MF).
2. ICT expenditure: a) the number of ICT personnel for operations and maintenance, and b) total ICT costs.
3. ICT assets scale: a) number of workstations, b) the combined scale factor and c) TIR cost (Hardware/software cost)

In Table 4.1 the 10 possible combinations of measurements for hypothesis H1 and proxies P1-P3 are represented with “ICT”: excluded is the combination of Total ICT costs as ICT expenditure measure with TIR costs as measure of the scale of ICT assets, because the TIR costs are included in the Total ICT costs (“xxx”). For the analyses of hypothesis H2 there are 2 combinations, indicated in Table 4.1 with “OP” (Organization Performance).

<table>
<thead>
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<th>management policy</th>
<th>expenditure construct</th>
<th>Scale of ICT assets</th>
<th>number WS</th>
<th>combined scale</th>
<th>TIR costs</th>
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In the following chapter the analyses and findings will be presented.