Economies of scale in ICT: how to balance infrastructure and applications for economies of scale in ICT and business

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3 CONSTRUCTS, HYPOTHESES AND PROXIES

3.1 Introduction

In this chapter we will define the basic hypothesis H1 of this research concerning the relations between (1) efficacy of ICT management policies, the (2) ICT expenditure and the (3) scale of ICT assets. Subsequently these three constructs will be further elaborated: for every construct an additional proxy is defined as a further specification and refinement of hypothesis H1. ICT expenditure will be defined using the theory of Total Cost of Ownership, according to Maanen and Berghout (2001). The definition and measurement of the scale of ICT assets will be elaborated based upon theories of complexity. The efficacy of ICT management policies, concerning ICT infrastructure and ICT organization will be based upon the theories treated in chapter 2. Furthermore hypothesis H2 between the (1) efficacy of ICT management, the (3) scale of ICT assets and the (4) Organization performance is defined. Finally the relations between constructs, hypotheses and proxies are made explicit in a research model.

3.2 Basic hypothesis (H1)

In this section we will first elaborate some principles of economies of scale, as presented in the theory section in chapter 2. Afterwards the basic hypothesis H1 will be derived. In Figure 3.1 the relation between scale and expenditure is represented, based on McConnell (1945) and Stigler (1958). In Figure 3.1 the positive and negative effects of Figure 1.2 are illustrated: if scale < S1 then economies of scale are stronger than diseconomies of scale; if scale > S2 then diseconomies of scale are stronger; if S1 <= scale <= S2 then there is a balance between the two effects. It is however obvious that these two effects, considered separately, are present at every scale level and are affected by ICT management policies.
The basic hypothesis in this research study is that the efficacy of ICT management policies determines the productivity of the operational ICT conversion process, thus:

(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.

And vice versa,

(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.

Next, we will discuss the hypothesis in more detail. To explain the transformation trajectory from inputs to outputs (Figure 1.2), we use a process perspective (Melville et al. 2004) and a production function. In prior work on the ICT productivity impact, production functions have been used to relate output to several inputs, including ICT (Mukhopadhyay et al. 1997; Brynjolfsson and Hitt 2003; Haynes and Thompson 2000; Wagner and Weitzel 2007). The hypotheses can be defined in terms of a Cobb-Douglas production function (Cobb and Douglas 1928) where:

Scale of ICT assets = x
ICT expenditure = y

Consequently, \( y = a \cdot x^b \), and:

Low efficacy of ICT management policies: diseconomies of scale and \( b(\text{low}) > 1 \) (H1)
High efficacy of ICT management policies: economies of scale and \( b(\text{high}) < 1 \) (H1’)

![Figure 3.1 Relation between scale ICT assets and ICT expenditure](image-url)
In Figure 3.2 these relations are depicted graphically by the unceasing lines. The dotted line in Figure 3.2 for all organizations has the same shape as the line in Figure 3.1.

![Graph showing ICT expenditure, ICT assets, and ICT management policies](image)

**Figure 3.2 ICT expenditure = f (ICT assets, ICT management policies)**

So Figure 3.1 can be translated into the low efficacy policies line in Figure 3.2 when \( S_1 = S_2 = 0 \), and into the high efficacy policies line when \( S_1 \to \infty \). Thus the assumptions with respect to hypothesis H1 are:
- Organizations where the efficacy of ICT management policies is high never reach point S1.
- To organizations where the efficacy of ICT management policies is low applies: \( S_1 = S_2 = 0 \).

Note that we will not investigate the exact form of the dotted line for all organizations in Figure 3.2 (the line in Figure 3.1). There is a debate in software engineering about the question why this isn’t a straight line (Kitchenham 2002). In that case the effects of economies and diseconomies of scale are equally strong at all scales. Also in that situation we can maintain our hypothesis H1, so the exact form of the line in Figure 3.1 is not important for this research.

In the next chapters the three constructs will be further elaborated.

### 3.3 ICT expenditure (P1)

In this section proxy P1 concerning the definition and measurement of ICT expenditure will be formulated. Different models of Total Cost of Ownership (TCO) assessment and benchmarking are described by Maanen and Berghout (2001), David et al (2002), and Gartner Consulting (2007). The TCO of an organization can be defined as all the costs associated with
the ownership and use of ICT by the organization over a certain period of time. These models distinguish themselves from the general cost models in that they consider all costs of a certain ICT object (facility, system or component) over the entire life cycle of this object. TCO models force one to consider ICT expenditure beyond the initial investment, i.e. throughout the entire life cycle of the information systems. Furthermore, they predefine the cost categories and, consequently, help one not to overlook particular types of costs. The actual value that is measured depends on both the timeframe and the point of reference. For example, an ICT organization that provides a certain information system will experience different costs and a different TCO value than the individual business units using this system. In this research the following types of costs are considered:

a) Total ICT expenditure (= sum of hardware/software and personnel, including innovation): an important goal of ICT management is to minimize the Total ICT expenditure at a given scale of ICT assets. This results in the “total productivity” (Tangen 2005).

b) Costs of ICT personnel engaged in operations and maintenance: the relation between ICT management practices and operational ICT staffing levels is an important research topic (IDC 2007). This results in the “operational labour productivity” (Tangen 2005).

It is assumed that the FTE (Full Time Equivalent) costs per year concerning ICT operations and maintenance is a better estimator of ICT expenditure than the total ICT costs per year, because the scale of ICT assets is the only determinant of the FTE costs of ICT operations and maintenance. During one particular year, a major project may have a great impact on the total ICT costs. The ICT assets created by this project, however, could well remain in operation for many more years to come. Therefore, the following proxy assumption concerning ICT expenditure can be defined:

(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.

P1 implies that hypothesis H1 can be better validated when ICT expenditure is defined by the human resources required for ICT operations and maintenance than by the total ICT costs.

3.4 Scale ICT assets (P2)

In this section we will formulate proxy P2 concerning the definition and measurement of the scale of ICT assets. ICT assets are defined by Soh and Markus (1995) as (1) useful, well-designed applications, (2) flexible ICT infrastructures with good “reach” and “range” (Keen 1991, Weill and Broadbent 1998), and (3) high levels of user ICT knowledge and skills. As the complexity growth of ICT assets is a source of diseconomies of scale, we will define complexity in relation to the scale of ICT assets. In this section we will explain how the curves in Figure 3.2 arise, based on more or less proportional growth of complexity in relation to the scale of ICT assets.

As stated in theoretical section about complexity in chapter 2, complexity can be defined as the number of different elements and relations (the “ontological” view). As ICT assets can be considered as a system of interacting elements, we can state the following:

Complexity ICT assets = f(scale and relations concerning ICT assets).
With respect to benchmarking organizations of the same type (for example Housing Corporations), we believe that the levels of user ICT knowledge and skills are comparable in organizations of the same kind, because their business processes are similar. (This assumption will be discussed in section 6.3.1). So the differences in the complexity of organizations of the same scale are determined by the relations concerning ICT infrastructure elements, applications and users.

The second view on complexity is based on the quantity of information (“descriptive” view) to describe the vital system (Ashby 1973). The quantity of information to describe the ICT assets is assumed to depend on the cost of the ICT assets. So in this view the scale of ICT assets is measured by the cost of ICT assets.

These views on complexity will be further detailed in the next sections.

3.4.1 “Ontological” complexity view based on relations

In this section the “ontological” complexity of ICT assets is assumed to be dependant on the relations concerning ICT infrastructure elements, applications and users. First we will analyze the relation between scale and complexity in general. Afterwards this will be applied to the ICT environment.

Relation between scale and complexity in general

In Figure 3.3 an object model is presented of a system, consisting of \( N \) elements, maximum \( N(N-1) \) relations between elements, \( N_t \) element types and maximum \( N_t(N_t-1) \) relations between element types.

\[
\begin{align*}
N_t &= \text{variety} = \text{number of element types} \\
N_t(N_t-1)^{pt} &= \text{number of relation types} \\
N &= \text{scale} = \text{number of elements} \\
N(N-1)^p &= \text{number of relations}
\end{align*}
\]

![Object model of a system with elements and relations](image)

Figure 3.3 Object model of a system with elements and relations
Definitions of scale, relations and variety:
Scale = number of elements = N
Element relations = N*(N-1)*p, where p is the percentile [dimensionless] of relations between elements (if p=0 then there are no relations, if p=1 then every element is related to every other element, if 0<p<1 then some elements are related to some other elements, dependant of the value of p).

Variety = number of element types = Nt.
Element type relations = Nt*(Nt-1)*pt, where pt is the percentile of relations between element types (if pt=0 then there are no relation types, if pt=1 then every element type is related to every other element type, if 0<pt<1 then some element types are related to some other element types, dependant of the value of pt).

We assume that in general there is a variety growth when there is a scale growth. This can be expressed as: Nt = q*N (the lowest possible value of q=1/N when Nt=1 and the highest possible value of q=1, when Nt=N). The factor q is dimensionless.

Backlund (2002) defines complexity thus: “Since complexity is something perceived by an observer, the complexity of the system being observed is, one could say, a measure of the effort, or rather the perceived effort, that is required to understand and cope with the system.”
Using this concept, we define the effort to understand and cope with the system as the effort to understand and cope with elements, relations, element types and relation types.
This can be formalized as follows:

Complexity = N*a + N*(N-1)*p*b + Nt*at + Nt*(Nt-1)*pt*bt.

Where a, b, at and bt are the average effort to understand one element, one relation, one element type respectively one relation type.
However, the theory of economies of scale assumes that specialization leads to lower effort at higher scale: N2>N1 \Rightarrow (a_2<a_1 and b_2<b_1). This does not hold for element types, as they are all unique.
So the values of a and b are dependant of the values of N: a_N and b_N
A more precise definition of complexity is thus:

Complexity = N*a_N + N*(N-1)*p*b_N + Nt*at + Nt*(Nt-1)*pt*bt

This can be written (using Nt=q*N) as:

Complexity = N*a_N + N*(N-1)*p*b_N + q*N*at + q*N*(Nt-1)*pt*bt
= N*(a_N - p*b_N + q*at - q*pt*bt) + N^2*(p*b_N + q^2*pt*bt)

This can be further simplified to:

Complexity = N * (Factor 1) + N^2 * (Factor 2),
with:
Factor 1 = a_N - p*b_N + q*at - q*pt*bt
Factor 2 = p*b_N + q^2*pt*bt

The relation between scale (N) and complexity is depicted in Figure 3.4.
If the effect of economies of scale (caused by diminishing values of $a_N$ and $b_N$ at greater values of $N$) is stronger than the effect of diseconomies of scale (caused by $N^2$) then the resulting curve has the “less than proportional” form, else the resulting curve has the “more than proportional” form.

![Figure 3.4 Relation between scale and complexity](image)

**Figure 3.4 Relation between scale and complexity**

Next we will find out whether the curves of Figure 3.4 also hold in the case of a system of ICT assets.

*Relation between scale and complexity in the ICT environment*

ICT assets are considered as a system of interrelated ICT infrastructure elements, applications and users. The relation between applications and infrastructure elements can be defined using the concept of services, which is described by various authors (Weill and Broadbent 1998; Dedene et al 2004). The elements in Figure 3.3 will be translated according to the IM framework at the operational level (Figure 2.9) in resources, services and users, see Figure 3.5. In this figure a difference is made between elements (users, services and resources) and element types (user types, service types and resource types) as in Figure 3.3:

At the operational level in Figure 2.9 and in Figure 3.5 we have the following entities:

- Individual *users* are part of the Business. For example a person using the financial application SAP.
- The application on the user-interface, and defined as user *service*, delivers Information to individual users. For example SAP on the desktop.
- The user service is made up by different mainly infrastructural Technological *resources*. For example the server with the SAP database.
At a higher level in Figure 2.9 and in Figure 3.5 we find the entity types that are the generalizations of the entities at the operational level; this is the level of the development/test/acceptation environment:

*User types* can be considered as the key users that perform the test and acceptation of the applications. For example the key user for a SAP module.

*User service types* are the applications in the development/test/acceptation environment. For example the SAP module in the development/test/acceptation environment.

*Resource types* are the mainly infrastructure resources in the development/test/acceptation environment, that together provide for the user service type. For example the test server with the SAP test database.

The scale of the elements (*number of elements*) of the system in Figure 3.5 is defined as the cardinality of the sets of elements at the operational level: the number of users (o), the number of user services (n) and the number of resources (m).

The *number of relations* of the system in Figure 3.5 is defined as the cardinality of the sets of relations at the operational level: between users and user services (pus\*o\*n, where pus is the percentile of user-service combinations) and between user services and resources (psr\*n\*m, where psr is the percentile of service-resource combinations).

The variety of the elements (*number of element types*) of the system in Figure 3.5 is defined as the cardinality of the sets of element types: the number of user types (ot), the number of user service types (nt) and the number of resource types (mt).

The *number of relation types* of the system in Figure 3.5 is defined as the cardinality of the sets of relations at the type level: between user types and user service types (pust\*ot\*nt, where pust is the percentile of user type - server type combinations) and between user service types and resource types (psrt\*nt\*mt, where psrt is the percentile of service type – resource type combinations).

There are 1-n relations between the type level and the instantiations at the operational level.
The complexity of the ICT system in Figure 3.5 at the operational level is determined by the effort (ICT labour) to handle the various elements and relations:

Number of different users (o). Every user needs to be administrated and needs more or less support, independent of the usage of the services, that generates a fixed amount of work per user (au). This type of effort (o*au) is called user maintenance.

Number of different user services (n). For every service there is a fixed amount of effort to maintain the service (as), independent of the number of users. This amount of effort (n*as) is defined as service maintenance.

Number of different resources (m). Every resource needs to be installed and maintained (effort ar), independent of the usage of the resource by services. We call this (total effort m*ar) resource maintenance.

Service-variety of users (the different user services per user (total pus*o*n)). Every service to a user needs more or less support; this is the variable amount of effort (bus) per user, dependant on the amount of service usage by the user. We call this (total effort pus*o*n*bus) functional user service support.

Resource-variety of user services (the different resources per user service (total psr*n*m)). Every resource for a user service needs more or less effort; this is the variable amount of effort (bsr) to assemble the user service, dependant on the amount of resource usage for the user service. We call this (total effort psr*n*m*bsr) technical service delivery.

The complexity of the ICT system in Figure 3.5 is at the type level determined by the effort (ICT labour) to handle the various element types and relation types:

User maintenance per user type (aut): the time to communicate with the user-representatives about the development, test and acceptance of the ICT system, independent of the services as such.
Total effort \( o \ast aut \).

*Service maintenance per service type* (ast): the time to develop and test a service type, independent of the resources and independent of the users.
Total effort: \( n \ast ast \).

*Resource maintenance per resource type* (art): time for installation, configuration, test and acceptance of the resource type independent of the service types.
Total effort \( m \ast art \).

*User support per user type per service type* (bust): the time to communicate with the user-representatives about development, test and acceptance of the service type.
Total effort \( pust \ast ot \ast nt \ast bust \).

*Service delivery per service type per resource type* (bsrt): the time to develop and test the configuration of the resource type with respect to the service type.
Total effort \( psrt \ast nt \ast mt \ast bsrt \).

Total complexity =
\[ o \ast au + n \ast as + m \ast ar \\
+ pus \ast o \ast n \ast bus + psr \ast n \ast m \ast bsr \\
+ ot \ast aut + nt \ast ast + mt \ast art \\
+ pust \ast ot \ast nt \ast bust + psrt \ast nt \ast mt \ast bsrt \]

We will show now that the structure of this formula is the same as:

Complexity (Figure 3.4) = \( N \ast \) (Factor 1) + \( N^2 \ast \) (Factor 2)

First we will define an overall scale variable \( N \) with \( o = c_u \ast N \) and \( n = c_s \ast N \) and \( m = c_r \ast N \),
where \( c_u \) and \( c_s \) and \( c_r \) are factors [dimensionless] to determine the specific values of \( o \) and \( n \) and \( m \) in relation to \( N \).
The same assumption holds for an overall scale variable \( N_t \) with \( ot = c_{u_t} \ast N_t \) and \( nt = c_{s_t} \ast N_t \)
and \( mt = c_{r_t} \ast N_t \).

Now we can translate the complexity as \( f(o,n,m,ot,nt,mt) \) in \( g(N,N_t) \):
Total complexity =
\[ c_u \ast N \ast au + c_s \ast N \ast as + c_r \ast N \ast ar \\
+ pus \ast c_u \ast N \ast c_s \ast N \ast bus + psr \ast c_s \ast N \ast c_r \ast N \ast bsr \\
+ ct_u \ast N_t \ast aut + ct_s \ast N_t \ast ast + ct_r \ast N_t \ast art \\
+ pust \ast ct_{u_t} \ast N_t \ast ct_s \ast N_t \ast bust + psrt \ast ct_s \ast N_t \ast ct_r \ast N_t \ast bsrt \]

This can be written more simply as:
Total complexity =
\[ N \ast (c_u \ast au + c_s \ast as + c_r \ast ar) \\
+ N^2 \ast (pus \ast c_u \ast c_s \ast bus + psr \ast c_s \ast c_r \ast bsr) \\
+ N_t \ast (ct_u \ast aut + ct_s \ast ast + ct_r \ast art) \\
+ N_t^2 \ast (pust \ast ct_{u_t} \ast ct_s \ast bust + psrt \ast ct_s \ast ct_r \ast bsrt) \]

Now we can see clearly that Total complexity depends on \( N \), \( N_t \), \( N^2 \) and \( N_t^2 \). We can define this still more simply by assuming that \( N_t = q \ast N \), so the number of types \( N_t \) grows
proportionally with the scale N. The factor q is dimensionless. Then the formula gets the following form:

Total complexity =
\[ N^*(c_u^*a_u + c_s^*a_s + c_r^*a_r) \]
\[ + N^2*(pus^* c_u^* c_s^*bus + psr^* c_s^*c_r^*bsr) \]
\[ + N^*q^*(c_t^u^*a_{tu} + c_t^s^*a_{ts} + c_t^r^*a_{tr}) \]
\[ + N^2*q^2*(pust^* c_t^u^* c_t^s^*bust + psrt^* c_t^s^* c_t^r^*bsrt) \]

This can be written as:

Total complexity =
\[ N^*(c_u^*a_u + c_s^*a_s + c_r^*a_r + q^*(c_t^u^*a_{tu} + c_t^s^*a_{ts} + c_t^r^*a_{tr})) \]
\[ + N^2*(pus^* c_u^* c_s^*bus + psr^* c_s^*c_r^*bsr + q^2*(pust^* c_t^u^* c_t^s^*bust + psrt^* c_t^s^* c_t^r^*bsrt)) \]

Now the structure of the formula is:

Total complexity = \( N^* \) (Factor 1) + \( N^2 \) (Factor 2),
with:
Factor 1 = \( c_u^*a_u + c_s^*a_s + c_r^*a_r + q^*(c_t^u^*a_{tu} + c_t^s^*a_{ts} + c_t^r^*a_{tr}) \)
Factor 2 = \( pus^* c_u^* c_s^*bus + psr^* c_s^*c_r^*bsr + q^2*(pust^* c_t^u^* c_t^s^*bust + psrt^* c_t^s^* c_t^r^*bsrt) \)

We discussed already the assumption that the diminishing values of \( a_u, a_s, a_r, bus \) and \( bsr \) at greater values of N are responsible for the economies of scale. So a more precise definition is:

Factor 1 = \( c_u^*a_u^N + c_s^*a_s^N + c_r^*a_r^N + q^*(c_t^u^*a_{tu} + c_t^s^*a_{ts} + c_t^r^*a_{tr}) \)
Factor 2 =
\[ pus^* c_u^* c_s^*bus^N + psr^* c_s^*c_r^*bsr^N \]
\[ + q^2*(pust^* c_t^u^* c_t^s^*bust + psrt^* c_t^s^* c_t^r^*bsrt) \]

If the effect of economies of scale (caused by diminishing values of \( au^N, as^N, ar^N, bus^N \) and \( bsr^N \) at greater values of N) is stronger than the effect of diseconomies of scale (caused by \( N^2 \)) then the resulting curve in Figure 3.4 has the “less than proportional” form, else the resulting curve has the “more than proportional” form.

The dimension of Factor 1 is the same as the dimension of \( a \) ([hour/piece] or [€/piece] in different variants \( au, as, ar, aut, ast \) and \( art \)), because \( c, p \) and \( q \) factors (in different variants) are dimensionless. This also holds for the dimension of Factor 2, which is the same as the dimension of \( b \) ([hour/piece\(^2\)] or [€/piece\(^2\)] in the variants \( bus, bsr, bust \) and \( bsrt \)). So the dimension of Total complexity can be time [hour] or cost [€].

In the next section we will define a view on complexity that is based on the amount of information to manage ICT assets.
3.4.2 “Descriptive” complexity view based on the quantity of information

In this view complexity is determined by the amount of information to describe a system (Asby 1973) of a certain scale, measured by the cost of the system. For the measurement of the amount of information we will use again the definition of Backlund (2002): “Since complexity is something perceived by an observer, the complexity of the system being observed is, one could say, a measure of the effort, or rather the perceived effort, that is required to understand and cope with the system”. So we assume there is a relation between the cost of the ICT assets and the effort of ICT management to understand and cope with the ICT assets.

In this section we will first translate the scale of ICT assets, defined in cost [€] to the effort of ICT labour (= complexity ICT assets), defined in cost [€].

Based on Figure 3.5, the following ICT labour activities are defined on the operational level:

- **Resource maintenance per resource** (average value \( a_{ri} \)): effort for resource \( i \): \( a_{ri} \)
- **Service delivery per service per resource** (average value \( b_{srij} \)): effort to let use resource \( i \) by service \( j \): \( b_{srij} \)
- **Service maintenance per service** (average value \( a_{sj} \)): effort for service \( j \): \( a_{sj} \)
- **User support per user per service** (average value \( b_{usjk} \)): effort to support the use of service \( j \) by user \( k \): \( b_{usjk} \)
- **User maintenance per user** (average value \( a_{uk} \)): effort to support user \( k \): \( a_{uk} \)

The effort of ICT-labour (= complexity ICT assets) will be determined based on the assumption that \( a_{ri} \), \( a_{sj} \), \( a_{uk} \), \( b_{srij} \) and \( b_{usjk} \) depend on the cost of the concerning ICT assets.

In Figure 3.6 an overview is presented of the ICT assets and ICT asset types. Now the relation between resource (types) and service (types) is represented by an arrow, to indicate that the cost of resource (types) are “translated” to service (types). The same holds for the relation between service (types) and user (types). The cost of the ICT assets are as follows:

- The cost \( (cr_{ri}) \) of the resource \( (r_{i}) \) is the starting point.
- The amount of resource usage per service \( (f_{i,j}) \) is the base of the distribution of the cost of resource \( (r_{i}) \) to the cost of service \( (s_{j}) \), see Figure 3.6, according to Dedene et al (2004).
- The cost \( (cs_{j}) \) of a service \( (s_{j}) \) is the sum of the distributed resource costs to that service.
- The amount of service usage per user \( (g_{j,k}) \) is the base of the distribution of the cost of service \( (s_{j}) \) to the cost of user \( (u_{k}) \) according to Dedene et al (2004).
- The cost \( (cu_{k}) \) of a user \( (u_{k}) \) is the sum of the distributed service costs to that user.

The relation between the cost of user services \( (cs_{1}, cs_{2}, \ldots, cs_{n}) \) and cost of resources \( (cr_{1}, cr_{2}, \ldots, cr_{m}) \) can be represented as follows (see Figure 3.6):

\[
(cs_{1}, cs_{2}, \ldots, cs_{n}) = F \ast (cr_{1}, cr_{2}, \ldots, cr_{m})
\]

where \( F \) is a \((n \times m)\) matrix filled with factors \( f_{i,j} \). The resource cost \( (cr_{i}) \) is distributed to the cost of the service \( (cs_{j}) \) according to a factor \( f_{i,j} \) with \( 0 \leq f_{i,j} \leq 1 \).
The relation between the cost of users \((cu_1, cu_2, \ldots, cu_o)\) and the cost of services \((cs_1, cs_2, \ldots, cs_n)\) can be represented as follows:

\[
(cu_1, cu_2, \ldots, cu_o) = G \times (cs_1, cs_2, \ldots, cs_n)
\]

where \(G\) is a \((o \times n)\) matrix filled with factors \(g_{j,k}\). The service cost \((cs_j)\) is distributed to the cost of the user \((cu_k)\) according to a factor \(g_{j,k}\) with \(0 \leq g_{j,k} \leq 1\).

The total cost of resources equals the total cost of services and the total cost of users:

\[
CA = cr_1 + cr_2 + \ldots + cr_m = cs_1 + cs_2 + \ldots + cs_n = cu_1 + cu_2 + \ldots + cu_o
\]

The total cost of ICT labour to handle technological resources is \(CLR\), to maintain services is \(CLS\), to deliver user support is \(CLU\), to assemble resources to services is \(CLSR\) and to deliver services to users is \(CLUS\). So total cost of ICT labour (= total complexity ICT assets at the scale (instantiation) level):

\[
CL = CLR + CLS + CLU + CLSR + CLUS.
\]

For every Euro [€] of resource cost an amount of \(CLR/CA\) [€] is spent on labour cost (resource complexity / scale ratio which is dimensionless).

The same holds for service labour:

\((CLS/CA\) is the service complexity / scale ratio),

and for user labour:

\((CLU/CA\) is the user complexity / scale ratio).

This rule can also be applied for resource-service labour:

\((CLSR/CA\) is the resource-service complexity / scale ratio),

and for service-user labour:

\((CLUS/CA\) is the service-user complexity / scale ratio).

Thus the ICT labour cost [€] for resource \(i\): \(ar_i = cr_i \times CLR/CA\).

For service \(j\): \(as_j = cs_j \times CLS/CA\)

And for user \(k\): \(au_k = cu_k \times CLU/CA\)

For resource \(i\) – service \(j\): \(bsr_{i,j} = f_{i,j} \times cr_i \times CLSR/CA\)

For service \(j\) – user \(k\): \(bus_{j,k} = g_{j,k} \times cs_j \times CLUS/CA\)
Based on Figure 3.5 and Figure 3.6, the following ICT labour activities are defined on the variety-level:

- **Resource maintenance per resource type** (average value $\text{art}_{it}$): effort for resource type $i_{t}$: $\text{art}_{it}$
- **Service delivery per service type per resource type** (average value $\text{bsrt}_{it,jt}$): effort to let use resource type $i_{t}$ by service type $j_{t}$: $\text{bsrt}_{it,jt}$
- **Service maintenance per service type** (average value $\text{ast}_{jt}$): effort for service type $j_{t}$: $\text{ast}_{jt}$
- **User support per user type per service type** (average value $\text{bust}_{jt,kt}$): effort to support the use of service type $j_{t}$ by user type $k_{t}$: $\text{bust}_{jt,kt}$
- **User maintenance per user type** (average value $\text{aut}_{kt}$): effort to support user type $k_{t}$: $\text{aut}_{kt}$

The effort of ICT-labour (= total complexity ICT assets at the type level) will be determined based on the assumption that $\text{art}_{it}$, $\text{ast}_{jt}$, $\text{aut}_{kt}$, $\text{bsrt}_{it,jt}$, and $\text{bust}_{jt,kt}$ depend on the cost of the concerning ICT asset types.

The cost of the ICT asset types are as follows:

- The cost ($\text{crt}_{it}$) of the resource type ($r_{it}$) is the starting point.
- The amount of resource type usage per service type ($\text{ft}_{it,jt}$) is the base of the distribution of the cost of resource type ($r_{it}$) to the cost of service type ($s_{jt}$).
- The cost ($\text{cst}_{jt}$) of a service type ($s_{jt}$) is the sum of the distributed resource type costs to that service type.
- The amount of service type usage per user type ($\text{gt}_{jt,kt}$) is the base of the distribution of the cost of service type ($s_{jt}$) to the cost of user type ($u_{kt}$).
The cost ($\text{cut}_{kt}$) of a user type ($\text{ut}_{kt}$) is the sum of the distributed service type costs to that user type.

The relation between the cost of user service types ($\text{cst}_1$, $\text{cst}_2$, …… $\text{cst}_{nt}$) and cost of resource types ($\text{crt}_1$, $\text{crt}_2$, ……. $\text{crt}_{mt}$) can be represented as follows (see Figure 3.6):

$$(\text{cst}_1, \text{cst}_2, ……. \text{cst}_{nt}) = \text{Ft} \times (\text{crt}_1, \text{crt}_2, …….\text{crt}_{mt})$$

where Ft is a (nt x mt) matrix filled with factors $f_{it,jt}$. The resource type cost ($\text{crt}_it$) is distributed to the cost of the service type ($\text{cst}_{jt}$) according to a factor $f_{it,jt}$ with $0 <= f_{it,jt} <= 1$

The relation between the cost of user types ($\text{cut}_1$, $\text{cut}_2$, ……. $\text{cut}_{ot}$) and the cost of service types ($\text{cst}_1$, $\text{cst}_2$, ……. $\text{cst}_{nt}$) can be represented as follows:

$$(\text{cut}_1, \text{cut}_2, ……. \text{cut}_{ot}) = \text{Gt} \times (\text{cst}_1, \text{cst}_2, ……. \text{cst}_{nt})$$

where Gt is a (ot x nt) matrix filled with factors $g_{jt,kt}$. The service type cost ($\text{cst}_{jt}$) is distributed to the cost of the user type ($\text{cut}_{kt}$) according to a factor $g_{jt,kt}$ with $0 <= g_{jt,kt} <= 1$

The total cost of resource types equals the total cost of service types and the total cost of user types:

$$\text{CAt} = \text{crt}_1 + \text{crt}_2 + ……. \text{crt}_{nt} = \text{cst}_1 + \text{cst}_2 + ……. \text{cst}_{mt} = \text{cut}_1 + \text{cut}_2 + ……. \text{cut}_{ot}$$

The total cost of ICT labour to handle technological resource types is CLRt, to maintain service types is CLSt, to deliver user type support is CLUt, to assemble resource types to service types is CLSRt and to deliver service types to user types is CLUSt. So total cost of ICT labour (= total complexity ICT assets at the type level):

$$\text{CLt} = \text{CLRt} + \text{CLSt} + \text{CLUt} + \text{CLSRt} + \text{CLUSt}$$

For every Euro [€] of resource type cost an amount of CLRt/CAt [€] is spent on labour cost (resource type complexity / scale ratio which is dimensionless).

The same holds for service type labour:

CLSt/CAt is the service type complexity / scale ratio.

And for user type labour:

CLUt/CAt is the user type complexity / scale ratio.

This rule can also be applied for: resource type - service type labour:

CLSRt/CAt is the resource type - service type complexity / scale ratio.

And for service type - user type labour:

CLUSt is the service type - user type complexity / scale ratio.

Thus the ICT labour cost [€] for resource type it: $\text{art}_{it} = \text{crt}_{it} \times \text{CLRt/CAt}$.

For service type jt: $\text{ast}_{jt} = \text{cst}_{jt} \times \text{CLSt/CAt}$

And for user type kt: $\text{aut}_{kt} = \text{cut}_{kt} \times \text{CLUt/CAt}$

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For resource type \( \text{it} \) – service type \( \text{jt} \): 
\[
\text{bsrt}_{\text{it},\text{jt}} = f_{\text{it},\text{jt}} \times \text{crt}_{\text{it}} \times \text{CLSRt/CAit}
\]
For service type \( \text{jt} \) – user type \( \text{kt} \): 
\[
\text{bust}_{\text{jt},\text{kt}} = g_{\text{jt},\text{kt}} \times \text{cst}_{\text{jt}} \times \text{CLUST/CAit}
\]

Until now we have determined the ICT labour cost as a measure of the complexity of every resource(type), service(type), user(type), resource-service relation(type) and service-user relation(type). This is based upon the assumption that there is a fixed cost-complexity ratio for every resource(type), service(type), user(type), resource-service relation(type) and service-user relation(type).

In the next section we will analyze the relation between the cost view and the number view on complexity.

### 3.4.3 Relation between the “ontological” and “descriptive” view on complexity

We now have 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 asset/relation(types) based on an “ontological” view on ICT assets is the starting-point; in the second way the cost of ICT asset/relation(types) based on an “descriptive” view on ICT assets is the point of departure to determine the effort of ICT labour. In the first way we use the average cost of ICT labour per asset/relation(type) and in the second case we use the average cost of ICT labour per € of asset/relation(types). Next the average cost values of the number view will be expressed in the specific cost values of the cost view. Every cost component is followed by an indication \( \text{ES} \) (economies of scale possibility) or \( \text{DES} \) (diseconomies of scale possibility). These indications are the same as already discussed in the number view (Figure 3.4).

The following ICT labour activities on the scale-level in Figure 3.5 (the number view) can be expressed in terms of Figure 3.6 (the cost view):

- **Resource maintenance** (\( m \) resources) = \( m \times \text{(average value ar)} = \sum ar_i \)
  \( \rightarrow \text{ES} \) (higher \( m \) \( \rightarrow \) lower \( ar \))

- **Service delivery** (\( n \) services, \( m \) resources, percentile \( \text{psr} \)) = \( \text{psr} \times n \times m \times \text{(average value bsr)} \)
  \[
  = \text{psr} \times \sum \sum bsr_{i,j} \rightarrow \text{DES} \text{ (quadratic effect } n \times m \text{ more important than } \text{ES} \text{ bsr)}
  \]

- **Service maintenance** (\( n \) services) = \( n \times \text{(average value as)} = \sum as_j \)
  \( \rightarrow \text{ES} \) (higher \( n \) \( \rightarrow \) lower \( as \))

- **User support** (\( o \) users, \( n \) services, percentile \( \text{pus} \)) = \( \text{pus} \times o \times n \times \text{(average value bus)} \)
  \[
  = \text{pus} \times \sum \sum bus_{j,k} \rightarrow \text{DES} \text{ (quadratic effect } o \times n \text{ more important than } \text{ES} \text{ bus)}
  \]

- **User maintenance** (\( o \) users) = \( o \times \text{(average value au)} = \sum au_k \)
  \( \rightarrow \text{ES} \) (higher \( o \) \( \rightarrow \) lower \( au \))
The same holds for ICT labour activities on the variety-level:

**Resource maintenance** (mt resource types) = \( mt \cdot (\text{average value } art) = \sum_{it=1}^{mt} art_i \)

\( \rightarrow \) DES (by higher mt)

**Service delivery** (nt service types, mt resource types, percentile psrt) = \( psrt \cdot nt \cdot mt \cdot (\text{average value } bsrt) \)

\( \rightarrow \) DES (by higher nt*mt)

**Service maintenance** (nt service types) = \( nt \cdot (\text{average value } ast) \)

\( \rightarrow \) DES (by higher nt)

**User support** (ot user types, nt service types, percentile pust) = \( pust \cdot ot \cdot nt \cdot (\text{average value } bust) \)

\( \rightarrow \) DES (by higher ot*nt)

**User maintenance** (ot user types) = \( ot \cdot \text{average value } aut \)

\( \rightarrow \) DES (by higher ot)

Total ICT labour in the cost view will be divided in two components: ICT labour 1 (which contains cost components with ES indications) and ICT labour 2 (which contains cost components with DES indications):

\[ \text{ICT labour 1} = \sum_{i=1}^{m} ar_i + \sum_{j=1}^{n} as_j + \sum_{k=1}^{o} au_k \]

\[ \text{ICT labour 2} = psr \cdot \sum_{i=1}^{m} \sum_{j=1}^{n} bsr_{ij} + pus \cdot \sum_{j=1}^{n} \sum_{k=1}^{o} bus_{jk} + \sum_{it=1}^{mt} art_{it} + \sum_{jt=1}^{nt} ast_{jt} + \sum_{kt=1}^{ot} aut_{kt} \]

\( \rightarrow \) DES (by higher mt*nt*ot)

Total ICT labour = ICT labour 1 + ICT labour 2

If the effect of economies of scale in ICT labour 1 is stronger than the effect of diseconomies of scale in ICT labour 2 then the resulting curve in Figure 3.4 has the “less than proportional”
form, else the resulting curve has the “more than proportional” form. The dimension of Total ICT labour is until now expressed in cost [€], but this can be translated in time [hour] if the appropriate tariffs per hour are used.

Before we continue with the definition of a proxy concerning the scale of ICT assets, we want to make three remarks, which can be derived from the complexity analysis above. Firstly, *standardization* (keep mt, nt and ot as low as possible) is the key to attain economies of scale and to avoid diseconomies of scale:

- The numbers of the same resources, services and users are greater when the types are as low as possible, so cost components ar, as and au will be minimized. This keeps ICT labour 1 as low as possible.
- All the ICT labour activities on the variety-level will be minimized when the numbers of types are as low as possible. This keeps ICT labour 2 as low as possible.

Secondly, according to the definition of Backlund (2002) complexity of a system is a measure of the perceived effort to understand and cope with a system; this implies that the knowledge of the observer (or controller) of the system plays a pivotal role in the perception of complexity.

Thirdly, the relation between scale and complexity, as represented in Figure 3.4 is a support for proxy assumption P1: indeed, this is a theoretical underpinning of the relation between scale and ICT expenditure by HIR operations, as stated in proxy assumption P1.

Now we have made acceptable the possibilities for (dis)economies of scale of ICT labour in relation to the scale of ICT assets for two views on complexity: firstly if the effort (complexity) of ICT labour depends on the *number* of ICT asset/relation(types) and secondly if the effort of ICT labour depends on the *cost* of ICT asset/relation(types). We assume that the number view gives a better approximation of the effort (complexity) of ICT labour than the cost view. The number view is based upon average values of cost per ICT asset/relation(type), while the cost view is based upon the cost of every individual ICT asset/relation(type). We think that the “Law of Large Numbers” (Simon 1977) will cause a higher correlation between scale and complexity (on a higher level of aggregation) in case of the number view compared with the cost view. This is in accordance with the findings of Alpar and Kim (1990): they concluded that the usage of cost ratios for ICT performance may be misleading. Therefore the following proxy assumption concerning the scale of ICT assets can now be defined:

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

P2 implies that hypothesis H1 can be better validated by the number of ICT assets than by the cost of hardware/software. Besides there is a restriction: it is not allowed to measure the (3) scale of ICT assets by the cost of hardware/software and at the same time measure the (2) ICT expenditure by the total ICT costs, because this total also contains the cost of hardware/software. In the research model (Figure 3.10) the 3 allowable relations between the two measures of the (3) scale of ICT assets and the two measures of the (2) ICT expenditure are delineated by arrows numbered 1, 2 and 3.
3.5 Efficacy of ICT management policies (P3)

In this section proxy P3 will be formulated, concerning the definition and measurement of the efficacy of ICT management policies. The efficacy of ICT management policies is defined in this research as the ability of ICT management to govern an efficient and effective conversion from operational ICT expenditure to ICT assets. This implies that effective policies create the conditions for an efficient and effective ICT conversion process. Efficacy therefore refers to both optimal utilization of technological resources and labour (or skills), which has become increasingly important with respect to the leverage of commodities. In the following sections we will deal with the infrastructure policy and the maturity of the ICT organization, as stated in the theory section about ICT management policies.

The organizations investigated in this research (Housing Corporations, Municipalities and Hospitals) have relatively low expenditures on ICT, and can therefore be categorized as an organization with a “utility view” (Weill and Broadbent 1998). This is in contrast with the enabling view on ICT shared by, for instance, financial services, which spend more than 15% of their total expenditures on ICT. According to Weill and Broadbent (1998) Housing Corporations, Municipalities and Hospitals should concentrate on infrastructure and transactional applications. Lower ICT spending organizations often run the risk (by technological aging) that their investments in infrastructure are insufficient to replace their outdated hardware/software and to procure modern tools for hardware/software management. As a result these organizations do not attain economies of scale and are unable to counterbalance the complexity growth. We therefore believe that investments in infrastructure have a positive effect on economies of scale and a negative effect on diseconomies of scale. In Figure 2.17 and the next text, we made plausible that organizations with an infrastructure focus (planned and flexible), have more standardized ICT assets than organizations with an application focus (chaotic and rigid). And in Figure 3.5 and the next text we showed that standardized ICT assets lead to less complexity and lower ICT expenditure.

The importance of the quality system increases with the scale of the ICT organization, simply because a more complex organization is more complex to manage. Other effects of additional quality systems are the specialization of labour and an increase in the bureaucratic nature of the organizational structure. We expect that quality systems have a positive effect on economies of scale and a negative effect on diseconomies of scale. However, complex quality systems are also susceptible to bureaucratic rigidity, which is often associated with the not-for-profit Housing Corporations, Municipalities and Hospitals studied in this research. And bureaucracy leads to diseconomies of scale (Williamson 1996).

We stated already that total cost of ICT management (total CoQ in Figure 2.16) behaves according to the left side curve in Figure 2.16. The organizations that will be investigated in this research have relatively low ICT budgets and have relatively low quality levels, so we think that improving the COBIT maturity level will lower the total cost of ICT management. But we can also see in Figure 2.16 that this curve is almost horizontal in the neighborhood of the minimum. So the higher the maturity level, the less is the saving in ICT management costs, until the costs rise again at the right side of the minimum.

It can be stated that neglecting the infrastructure has more influence on the level of ICT expenditure than a low organizational maturity, because investments in infrastructure (in low ICT spending organizations) have both a positive effect on economies of scale and a negative effect on diseconomies of scale. A quality system (in a bureaucratic culture) has a positive
effect on economies of scale and only a moderately negative effect on diseconomies of scale caused by bureaucratic rigidity. Furthermore, the subjective determination of the maturity level, as described in section 1.4, gives rise to less confidence in the reliability of the maturity factor. Therefore, the following proxy assumption about the ICT management policies construct can be defined:

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

P3 implies that hypothesis H1 can be better validated when ICT management policies are defined by investments in infrastructure rather than by the maturity level of the ICT organization.

We can consider proxy P3 from a cybernetic point of view, as explained in Figure 2.17. The organizations investigated in this research have a relatively low level of ICT spending and ICT maturity. So these organizations can be positioned in the “Planned (P)” or “Rigidity (R)” quadrant of Figure 2.17. Thus the only important variable is the level of Infrastructure, to differentiate between P and R. This is in line with proxy P3.

3.6 Business productivity (H2)

We used the Information management framework (Maes 1999) to define the scope of the research model (see Figure 2.7). At the operational level services are delivered to the users in the business by TIR (Technical Information Resources). The HIR (Human Information Resources) in the nine blocks can be divided in two groups:

- Business HIR: this includes the “competitive process”, see Figure 2.14.
- Information/Communication and Technology HIR: this includes the “ICT conversion process” and the support of the “ICT use process”, see Figure 2.14.

ICT assets are defined as infrastructure, applications and users with appropriate knowledge (Soh and Markus 1995). ICT assets are delivered to users in the form of services (Figure 2.7): infrastructure services, application services and knowledge to use the services. The TIR is delivering infrastructure and application services; the HIR at operational I/C level is delivering the appropriate knowledge. The users at operational business level consume the services and translate them ultimately to some output of the organization, to be measured in the form of organization performance. The measurement of the services is a difficult point, especially as far as applications and knowledge is concerned. What is the value of applications for users? How can “ICT impacts” (see Figure 1.1 and Figure 2.14) be measured? See for example DeLone and McLean (1992, 2002) on this point. We assume that more and better services lead ultimately to more and better organization performance and we will not investigate ICT impacts.

Concerning the composition of the services there is always a tension between Business and Technology: users want their application services as specific as possible, to be able to optimize their business process; the ICT management prefers to deliver the application services as generic as possible, to be able to optimize the ICT processes. In Figure 2.15 the relation between infrastructure and applications is represented using the classification of Weill and Broadbent (1998). In this classification the shared and standard (transactional)
applications are defined as part of the (extended) infrastructure. However in our research, due to availability of empirical data, we define the shared and standard applications as part of the whole of applications.

Thus the Business management wants to spend as much as possible on applications in order to optimize the business processes, and the ICT management wants to spend enough on infrastructure, in order to optimize ICT processes (as explained in section 2.7.3). From the point of view of the whole organization this can be defined as an optimization problem: what is the optimal spending on applications and infrastructure? In this research the investments in ICT infrastructure (as a measure of efficacy ICT management policies) were measured by the infrastructure part of the total ICT costs during the last years. This measure is called the Infrastructure Factor (IF), which will be further explained in chapter 4. In Figure 3.7 the relation between the Infrastructure Factor (IF) and Costs of ICT processes is represented: we assume that these costs decrease with increasing IF. On the other hand the Costs of Business Processes increase with increasing IF (and decreasing application functionality). Therefore there must be a minimum for the total costs (the sum of business costs and ICT costs) at a certain value of IF. We suppose there is a minimum value (Min) for IF below which the ICT expenditures rise more steeply and a maximum (Max) above which the business expenditures rise more steeply. Then there must be an area between Min and Max where total costs are more or less the same.

![Figure 3.7 Relation between Infrastructure Factor and costs](image)

For the determination of Min and Max we will use a process perspective and explain first the relations between input and output of the ICT conversion process and of the business processes (see Figure 1.2).
In chapter 3, basic hypothesis (H1), we explained the following:
The relation between the output \((x)\) and the input \((y)\) of the ICT conversion process is assumed to be a function of the form \(y=ax^b\), see Figure 3.2. We think that in case of a low value of the infrastructure factor (IF) there is an effect of diseconomies of scale, therefore:
\[ b(\text{low efficacy ICT management policies}) = b(\text{IF low}) > 1. \]
In case of a high value of the infrastructure factor (IF) we assumed there is an effect of economies of scale, therefore:
\[ b(\text{high efficacy ICT management policies}) = b(\text{IF high}) < 1. \]
Hypotheses H1 is based on this idea,
with \(x = \text{ICT assets}\),
and \(y = \text{ICT expenditure} \) and productivity ICT conversion process = \(x/y\).

The relation between the input \((x)\) and the output \((y)\) of the Business processes is also assumed to be a function of the form \(y=ax^b\), see Figure 3.8.
Now \(x = \text{ICT assets}\),
and \(y = \text{Organization performance} \) and productivity business processes = \(y/x\).

Therefore productivity business processes = \(y/x\).
We think that in case of a low value of the infrastructure factor (IF) there is an effect of economies of scale (because of high spending on Applications), therefore \(b(\text{IF low}) > 1\); in case of a high value of the infrastructure factor (IF) there is an effect of diseconomies of scale (because of low spending on Applications), therefore \(b(\text{IF low}) < 1\). Note that the shape of the curves (in terms of IF low and IF high) in Figure 3.8 is opposite to the shape of the curves in Figure 3.2.

Also in the Business processes we assume the “ontological” complexity (see Figure 3.3) is growing with the square of the scale, which is the cause of diseconomies of scale, with lower than average Organization performance at higher scale as a result. If however these processes are structured and supported by applications, then economies of scale can be attained. Therefore the following hypothesis can be formulated:

(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.

And vice versa,

(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 will use “Turnover” as a measure of organization performance, to be able to compare this with the “Cost” of an organization. We assume that in the case of low IF (high spending on applications), the Margin (= Turnover - Cost) has a higher value than in the case of high IF (low spending on applications) at a certain value of ICT assets. According to Karimi et al (2007) “Greater IS resources … are positively associated with higher business process outcomes”. And Bharadway (2000) states: “Superior ICT capability will be associated with significantly higher profit ratios, and …. with significantly lower cost ratios”. Also Santhanam and Hartono (2003) and Kim (2004) are drawing the same conclusion. This is visualized in Figure 3.9. The reason is that the organization (in the business processes) is working more efficiently in the case of high spending on applications, with more application functionality. Therefore we assume that more efficiency will result in less cost and in higher turnover.

Let us now determine the values of Min and Max in Figure 3.7. We state that the value of Min is determined by the “Low efficacy ICT management policies” curve in Figure 3.2 for the ICT conversion process, because this is the diseconomies of scale curve. This curve can be considered as the “IF=Min” curve: organizations with an IF value less or equal to Min have diseconomies of scale in their ICT expenditure. Therefore, the points in Figure 3.7 with IF < Min have higher values of ICT costs. The determination of this Min (“low IF”) value is part of the verification process of hypothesis H1.

In the same way the value of Max is determined by the “high IF” cost curve for the Business processes in Figure 3.9, because this is the diseconomies of scale curve. The points in Figure 3.7 with IF > Max have higher values of costs Business processes. The “high IF” value of the cost curve in Figure 3.9 is the same “high IF” value of the turnover curve in Figure 3.9. And the determination of this Max (“high IF”) value is part of the verification process of hypothesis H2.
NB In the M&I dataset we do have Turnover and we do not have Costs to our disposition. So we are not able to formulate and analyze a hypothesis concerning Costs of the Business processes. Therefore we assume that in Figure 3.9 a lower IF (which means higher spending on Applications) leads to higher Turnover and lower Costs and thus higher Margin (as explained above and supported by references).

![Graph showing Turnover, Cost, and Margin](image)

**Figure 3.9 Relation between ICT assets versus turnover, cost and margin**

The practical importance of the values of Min and Max for the Infrastructure Factor as a measure of efficacy of ICT management policies is that an advice can be given to ICT managers concerning the optimal composition of investments in infrastructure and applications. This is particularly important in organizations with a low level of ICT spending, with a “utility view” on ICT. In this situation the values on Min and Max will possibly coincide, and then there is a delicate balance between investments in infrastructure and applications.

Now that we have defined our hypotheses and proxy assumptions in detail, we are able to demonstrate the research model.

### 3.7 Research model

In this paragraph we first give an overview of definitions and hypotheses. Afterwards follows a research model with the relations between hypotheses, constructs and proxies.
3.7.1 Definitions

Below follows an overview of definitions of important terms (*constructs are numbered and printed italic*).

**ICT conversion process** = conversion ICT expenditure to ICT assets (Soh and Markus 1995)

**Business processes** = (conversion ICT assets to ICT impacts) + (conversion ICT impacts to organization performance) = conversion ICT assets to organization performance

**ICT assets** = infrastructure + applications + users (ICT assets are defined by Soh and Markus (1995) as (a) useful, well-designed applications, (b) flexible ICT infrastructures with good “reach” and “range” (Keen 1991, Weill and Broadbent 1998), and (c) high levels of user ICT knowledge and skills.)

Infrastructure = infrastructure system delivering infrastructure services = Information technology components (hardware and software) + human ICT infrastructure = workstations + peripherals + infrastructure data communications + servers and storage + communications speech and video + facilities + operating systems and middleware + human resources (see Figure 2.15)

Applications = application system delivering application services = software and software services + interfaces + databases + human resources (see Figure 2.15)

(1) **Efficacy of ICT management policies** = ability of ICT management to govern an efficient and effective conversion from operational ICT expenditure to ICT assets. This implies that effective policies create the conditions for an efficient and effective ICT conversion process.

This is measured in the following ways:
- Investments in ICT infrastructure (as a result of the technology policy).
- Maturity of the ICT organization (as a result of the human infrastructure policy).

(2) **ICT expenditure** is defined in two possible ways:
- Total ICT costs (= sum of hardware/software and personnel, including innovation)
- Costs of ICT personnel engaged in operations and maintenance

(3) **Scale of ICT assets** is defined in two possible ways:
- Number of ICT assets.
- Cost of hardware / software (excluding cost of ICT human resources).

Complexity of ICT assets = effort of ICT labour to handle ICT assets (Backlund 2002) = f (scale of ICT assets)

(4) **Organization performance** = output of the “competitive process” (Soh and Markus 1995), in this research measured by the turnover of the organization.

Productivity = output / input (Chew 1988)

Productivity ICT conversion process = (3) scale ICT assets / (2) ICT expenditure
3.7.2 Hypotheses and proxies

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.
(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.

3.7.3 Relations between hypotheses, constructs and proxies

In this section the relations between hypotheses, constructs and proxies will be represented as part of a research model. The second proxy assumption (P2) is that the number of ICT assets is a better measure of the (3) Scale of ICT assets than the cost of hardware/software. There is however a restriction: it is not allowed to measure the (3) scale of ICT assets by the cost of hardware/software and at the same time measure the (2) ICT expenditure by the total ICT cost, because this total also contains the cost of hardware/software. In the research model (Figure 3.10) the 3 allowable relations between the two measures of the (3) scale of ICT assets and the two measures of the (2) ICT expenditure are delineated by arrows numbered 1, 2 and 3. So the fourth possible relation between the cost of hardware/software and the total ICT cost is not drawn. This implies that the scope of proxy P2 is restricted to the arrows 2 and 3 and that the scope of proxy P1 is restricted to the arrows 1 and 2. This also means that hypothesis H1 will be tested firstly by the combination of arrows 1 and 2 and secondly by the combination of arrows 2 and 3.

H1 and H2 are relations between constructs; P1, P2 and P3 are related to the definition of variables that measure a construct, serving as refinements of H1 in this respect. In the following chapter an additional proxy P2a will be defined, based on the way of measurement of the variable “number of ICT assets”.

The constructs, hypotheses and proxies elaborated are represented in a research model (Figure 3.10). The position of hypotheses H1-H2 (thick arrows) and proxies P1-P3 (thin arrows) in
relation to the respective constructs is indicated in Figure 3.10. The scope of P2a as a further refinement of the measurement of the number of ICT assets (which will be elaborated in the next chapter) is also indicated in Figure 3.10.

Figure 3.10 Research model

Next, we will relate our line of reasoning, hypotheses and approximations to the exploratory analysis of the data.