A TRANSCATION COST NASH EQUILIBRIUM MODEL FOR THE
ADOPTION OF INNOVATIVE INFORMATION TECHNOLOGY

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Abstract:

This paper investigates the problem of innovative information technology adoption in multi-
division organizations. Although innovative IT programs can increase benefits at the
organizational level, they may encounter the resistance at the divisional level. To explain this
situation, the paper propose an incentive-compatible general equilibrium model, named
Transaction Cost Nash Equilibrium (TCNE), for studying the intra-organizational economy.
From TCNE’s point of view, the paper reveals that due to the impact of IT program adoption,
divisions in an organization may have to adjust their efforts and so as their expected utilities will
change. Only when all divisions’ expected utilities do not decrease, the IT program adoption will
be feasible. As the incentive mechanism affects divisions’ utility function as well, it is possible
that the organization aligns their incentive plan to achieve the success of the IT program. A case
of computing facility upgrade is discussed to show the possible TCNE outcomes under different
conditions.

Keywords:

Innovative IT adoption, transaction cost Nash equilibrium, intraorganizational equilibrium,
incentive alignment
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1. Introduction

In this paper we propose a theory which explains why an organization adopting an innovative IT program should adjust the incentive plans for inter-divisional coordination in order to make the IT initiative feasible. Organizational examples of an innovative program in the IT domain include initiating software reuse programs in software development (Fichman and Kemerer 2001), the introduction of a knowledge management program (Hansen 2002), or more basic IT programs, such as the upgrade of information system with advanced hardware and software.

Although the innovative IT programs can bring in more benefits at the organizational level, they may not always be well accepted at the divisional level. It has been observed that when an organization decides to adopt an innovative program, the resistance within the organization may curtail the adoption. The reasons for the resistance could be rooted in organizational structure, inertia, and the knowledge of the program (Lynex and Layzell 1997).

One way to approach the topic of adoption is to study the intraorganization incentives that must be in place to promote adoption of the new program (Ba, Stallaert and Whinston 2001; Lewis and Seibild 1993). Although agency theory (Alchian and Demsetz 1972; Rose 1973; Hart and Holmström 1987) is applicable in this situation, the theory only solves the problem in a bilateral relationship, thereby generating a partial equilibrium of the economy in an organization. It does not take into account the side-effect on other agents caused by a change in one agent’s effort, as he adjusts his effort with the new incentive plan. This change may cause a failure of the existing intra-organizational equilibrium, since it involves the externalities between agents. The
alignment of incentive plan must consider global effects on the equilibrium of the organization among all agents (Holmström and Milgrom 1994).

In this paper we propose an inter-divisional Nash Equilibrium model, named transaction cost Nash equilibrium (TCNE), that subsumes general equilibrium (Arrow and Debreu 1954), transaction cost economics (Coase 1937; Williamson 1985), transaction cost equilibrium (Hahn 1971; Repullo 1988), and incentive mechanism design (Hurwicz 1973; Schmeidler 1980; Tian 2000, 2001) concepts to study IT adoptions from a normative perspective. We describe the adoption of an IT initiative as a process of equilibrium transition in an intra-organization economy, as it adapts to the impact of the innovation (Sabherwal, Hirscheim, and Goles 2001). A change in benefits would result from a change in resources, efforts, or incentives, which leads to a new equilibrium. Subject to organizational context, with the help of a properly aligned incentive plan, not all organizations require a significant investment in infrastructure change.

How do individual divisions maximize or fail to maximize their utility when adopting a new IT initiative? What effects does an incentive scheme at the division level have on the success of the new program? How can we explain success or failure to adopt a program using TCNE for inter-division transactions in an organization? These are main questions we attempt to elucidate in this paper.

The remaining structure of this paper is described as the following. Section 2 derives and constructs the TCNE model after a brief review of relevant economic theories. Section 3 applies the model to equilibrium analysis of IT adoption based on a case study. We conclude this paper in section 4.
2. An Incentive-compatible Transaction Cost Equilibrium Model

2.1 Theoretical Background

From the general equilibrium viewpoint, pure exchange economics, and its extension, welfare economics – initially developed by Arrow and Debreu (1954) – could be applied to explain the status of organizational management (Milgrom and Roberts 1992). Two concepts are important in the application of the theory to organization management. The first one is the optimal resource allocation defined as \textit{Pareto optimal}; another one is the general competitive equilibrium named as \textit{Walrasian equilibrium}, which is reachable via exchanges among agents. In organization management context, according to Milgrom and Roberts, the exchange can help coordination of production in a multidivisional organization.

Although general equilibrium is key to understand the impact of IT initiatives on organization management status, it has inherited four inadequacies. The first one is that the neoclassical economic assumptions, such as complete information and complete rationality, do not comply with the reality of modern organizations well (Demsetz 1997). Divisions in an organization normally possess limited information and have restricted ability to make decisions (Williamson 1985). The second inadequacy lies in the assumption of guileless self-interestedness, meaning the agents are not opportunistic. In reality, divisions and individuals in an organization must be opportunistic (rather than the limited scope of self-interested), and utility-maximizing (their own benefits are considered more important than that of the organization). The third inadequacy is that the transactions among agents are assumed to be costless. In fact, the managerial coordination and the resource allocation in an organization must come with transaction costs, which include \textit{coordination costs} and \textit{motivation costs} (Milgrom and Roberts 1992). Finally, Walrasian equilibrium is not considered incentive-compatible even
for classical economic environments when the number of agents is finite (Tian 2000). This is because of the assumption that the benefits agents receive are exogenous, and hence irrelevant to the effort they exert.

One of the research outcomes in customizing classical general equilibrium model for the application of the organization management is the transaction cost equilibrium model, which comes in two versions represented by Hahn (1971) and Repullo (1988) respectively. The two versions differ in the assumptions on how transactions costs incur and are charged. Transaction cost equilibrium, as its name suggests, is underpinned by transaction costs economics theory (Coase 1937), which assumes that: 1) agents are opportunistic, 2) their rationality is bounded (Kreps 1992), and 3) the transaction costs affect the operation of the economy as well as its equilibrium. The transaction cost equilibrium model enhances the classical general equilibrium with multi-period equilibria with costs for transactors. Nevertheless, the transaction cost equilibrium theory does not address how incentives may be aligned so that the agents’ activities are compatible to their incentives (benefits).

Another economic research thread extending the general equilibrium theory has added incentive compatible ingredients (Hurwicz 1960, 1973; Schmeidler 1980; Suh 1995; and Tian 2000). This makes the application of the theory to organizational management problems feasible. The original idea of incentive mechanism design for the general equilibrium is to feedback profits (in addition to the value from consumption) to the agents in the economy based on their purchase of commodities. In this way, the benefit is based on the outcomes from the effort of the agents, thus making the effort an endogenous variable. By establishing the feedback from benefits to the effort level of agents, the mechanism can result in Pareto efficient allocations for the economy, i.e., Nash equilibrium (Tian 2000). This idea is similar to that of principal agent
theory, but differs in that the problem scope has been extended to the whole economy. But even the Tian model is not without problems. Though the (Tian) model is incentive-compatible, it does not take into account of transaction costs and has restricted its application to the inter-organizational equilibrium study. Thus, in the follow-up sections we are to construct an incentive-compatible equilibrium model that combines two streams of economic literature. We then adapt it to explain innovative IT initiative adoption, and discuss its the explanatory power using the concept of intra-organizational equilibrium.

2.2 An Incentive-Driven Organization Management Structure

Regardless its complexity, an organization generally consists of several organizational components that work cooperatively to achieve the IS organization’s business goals. Here, we define such a component as division which is an economic entity in which no problem of interpersonal comparison of utility and of information transmission is considered to be relevant to the problem being examined, following a similar definition for actor by Grandori (2001). This definition of division includes the permanent structural components, such as the departments in the organization, as well as the temporal project-oriented groups that may across several departments.

**Assumption 1:** The divisions in an organization are self-interested and opportunistic. They attempt to maximize their own expected utility by exerting an appropriate effort regarding the resources allocated and the optimized yields.

Divisions consume resources allocated by the organization. We define a resource as an investment of manpower, capital, fixed assets, cash flow, the information for decisions in production and management, etc (Hunt 2000). A resource has two important characteristics. If a resource can be accumulated and later reused it is called reusable, e.g. reusable software
components. If a resource can be shared without degrading its value it is called *sharable*, e.g. databases. Note that reusability is the repeatedly use of the same resource over a long period, whereas sharability is the use of the same resource at the same (overlapped) time by several divisions. When accounting for available resources, it can be thought of that the total amount of available resources in an organization increases if some resources can be reusable and sharable.

**Proposition 1:** *The sum of resources used by each division is more than the total amount of resources allocated by the organization.*

As mentioned earlier, some resources are reusable and sharable by several divisions. Hence, these resources should be counted multiple times by use for each division. This implies that an organization that improves the sharability and reusability of resources between divisions can increase yields without increasing the amount of initial amount of resources that the organization procures.

A division generates output by its efforts with the consumption of resources. The outputs are goods or services, and are termed here as *yields*. A yield can be considered a function of a bundle of resources and the divisional effort. The organization has designated each division minimum levels of yields to guarantee the achievement of the business goals, which are defined as *designated yields* that are the goods or the services from a division meeting certain quantity and quality requirements. The need for a designated yield is the reason why the responsible division exists and why the organization endows resources to it.

In general, the expected utility function of a division is non-decreasing and concave with regard to resources and yields, but decreases with effort. The function is also sensitive to the organization’s evaluations and rewards of the yields. Given the allocation of resources and the criteria that an organization evaluates and rewards the contribution of divisions, a division can
optimize its effort to maximize the expected utility. Figure 1 presents the relationship among divisional utility, effort, resources and designated yields.

![Division's Indifferent curves and optimum effort level](image)

**Figure 1:** Division’s indifferent curve and optimum effort level

The above figure shows the relationships among divisional utility, effort, resources and yields, in which both resources and yields are simplified as a single variable for the better explanatory clarity. Division’s indifferent curves are combinations of different levels of effort and resource, which result in the same level of expected utility. The iso-yield curve, representing the level of designated yields, contains the combinations of effort and resource producing the same level of output. We can see that the division maximizes its utility as $U^*$ with the effort-resource pair $(E^*, R^*)$ to meet the designated yield. In an alternative choice $(E^H, R^l)$, the division receives a lower utility $U_1$.

**Assumption 2:** An organization maximizes its expected overall payoff by choosing a proper incentive plan applied to its divisions.

The organization is aware of the utility maximization strategy that divisions are applying. A higher yield without extra resource consumption or the same level of yield with less resource consumption is favorable to the organization. Since division efforts are not observable, the organization designs the incentive mechanism to promote efficient operational processes. An
incentive plan is a documented incentive mechanism dealing with 1) the promotion criteria that would motivate divisions to exert the proper effort to maximize the expected utility of all stakeholders and those of the organization as a whole, and 2) the necessary resource reallocation plan in each period to optimize the use of resources. Depending on the incentive plan, divisions consume resources and exert effort, and produce yields to achieve the organizational goals. The organization monitors divisions’ yields and adjusts the incentive plan to maximize its overall utility with regard to the observed divisional yields.

**Assumption 3:** Divisions are allowed to exchange their resources and yields under certain levels in order to optimize their expected utilities. However, due to the limitations in the available information and the ability, divisions may not always make optimal decisions, which is considered bounded rationality.

The initial resource allocation is not necessarily optimal. Therefore, coordination and mutual adjustments between divisions are required. This includes resource/yield exchanges via negotiations between divisions, where the excessive resources and the extra yields above the designated levels can be used by divisions for trading with the desired resources/yields from other divisions to save its effort. That is, in addition to simply trading with excessive resources, a division may produce more designated yields with these resources for exchanges with other divisions to improve its own productivity of the designated yields, as long as this will maximize the division’s expected utility. These inter-divisional activities in turn reduce divisions’ costs and are considered exchanges a division gives out its resources/yields for something from other divisions as the return. In this way, divisions can maximize their utility by exchanging their resources or yields and adjusting their efforts accordingly.

Figure 2 illustrates the above model showing how resources and incentive plan are applied to divisions. We only depict two representative divisions in the figure. The coordination
happens at two levels: inter-division level, and organization-division level. There is a feedback loop: yields – observed performance of divisions – incentive plan – effort – yields. From outside of the organization, only inputs and outputs of the organization are observable.

![Diagram](image)

**Figure 2.** An Incentive-Driven Model for A Multidivisional Organization

### 2.3 A Transaction Cost Nash Equilibrium Model for IT Adoption

To explain the situation with adopting an IT program, consider that the organization was in a state of equilibrium before the adoption. In the equilibrium the resource allocation, the effort level of divisions, divisional yields, and periodical exchanges between divisions are stable. Once an IT program is adopted, the impact will cause divisions to change their effort and resource/yield exchange structure to maximize their expected utilities. Then the previous equilibrium will shift to a new one.
**Definition 1:** A transaction price for inter-divisional exchanges within an organization is a shadow price,\(^1\) which is defined as a division’s marginal utility of a resource/yield. We normalize a transaction price in the value of its proportion in the summation of marginal utility of all resource/yields. In this way, the summation of the prices is equal to 1 and each transaction price is less than 1.

**Definition 2:** A transaction cost is defined as the cost in an inter-divisions exchange. It could be the cost in searching for a division for the exchange or the extra effort in price negotiation, etc. We also normalize a transaction cost with regard to its proportion in the summation of marginal utility of resources/yields.

**Definition 3:** An inter-divisional transaction cost Nash equilibrium in an organization with regard to an IT initiative program in a \(N\)-period transaction process consists of a transaction price matrix, a transaction cost matrix, an allocation of resources and efforts from the divisions that yields an output, and an incentive plan, such that, for every period,

A. The difference of the transaction prices between any two inputs is less than the minimum of the transaction costs from getting the resources elsewhere.

B. The transaction prices maximizes a division’s utility

C. Each output yielded from the effort for the incentive plan satisfies the designated yield level.

Condition A means that as long as the cost for a division to exchange resource/yield is greater than the utility increment from the exchange, the division will not proceed to do so because the exchange will not bring in more utility. It also implies that divisions may have different transaction prices for the same yield/resource because of the existence of transaction costs. Condition B is the consequence of condition A, because if the transaction prices do not maximize a division’s utility, the division will exchange its yields/resources until the

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\(^1\) Shadow price: It is a concept applied to situations where actual prices cannot be charged, or where actual prices charged do not reflect the real sacrifice made when some activity is pursued. In a perfectly functioning economy, market prices will be equal to marginal cost (see perfect competition), which itself represents the true cost to society of producing one extra unit of a commodity; it is equivalent to the value of the items that could have been made as alternatives to the last unit of the commodity produced, with the same resources. In the competitive economy, therefore, the market price of an item is equal to the opportunity cost of producing that item. In an economy which does not function perfectly, however, this is not so. More generally, shadow prices are used in valuing any item, which is implicitly rationed or constrained in some way. ([http://www.xrefer.com](http://www.xrefer.com))
optimization is reached. The consequence is the division’s transaction prices will be changed. Condition C is the constraint set by the organization.

As explained earlier, the model is based on the two assumptions in transaction cost economics – bounded rationality and opportunistic. The ingredients include the Nash equilibrium definition for the welfares economics with a finite number of firms (Tian 2000), and the multiple-period transaction cost equilibrium (Hahn 1971; Repullo 1988). The main differences of the definition of TCNE from other equilibrium definitions include: 1) divisional efforts are counted in the equilibrium, and 2) it characterizes intra-organizational equilibrium.

**Proposition 2:** *(The necessary and sufficient condition of TCNE)* When TCNE is reached, the marginal utility of effort is zero.

If the marginal utility for effort for an incentive plan is not equal to zero, the division can always change its effort to maximize its expected utility. This will change TCNE status until the marginal rate is 0.

**Proposition 3:** *Changing incentive plan will change TCNE.*

Changing the incentive plan change divisions’ utilities. Consequently, divisions need to take action to improve their utilities. This will cause a change in the TCNE. Proposition 4 implies that an organization can align its incentive plan for either better adoption of an IT program or improve the organization’s payoffs.

**Proposition 4:** *(The reachability of TCNE)* When organizational TCNE transits from one state to another, even though the organization’s overall benefit may increase, the new equilibrium may not necessarily be reachable if at least one division will be worse off.

If no division is worse off after the new IT initiative, there will be no resistance and the new equilibrium will bring the organization desirable profits. However, there is a possibility that some divisions will be worse off after an IT program adoption. Thus, the organization in the IT adoption context faces the feasibility problem of transition process. It must reconsider the
incentive plan, so that each division will be better off after the change. This is an incentive alignment issue as raised by Ba, Stallaert and Whinston (2001). If the new TCNE for the program is feasible, the second question the organization faces is how to choose the best incentive plan to maximize profits.

3. Equilibrium Analysis of IT Program Adoption

3.1 The effect of an IT program adoption on the equilibrium

The TCNE model defined in the last section provides a global perspective of impacts of new IT program on interdivisional equilibrium. In detail the impacts of an IT program adoption could be in three aspects:

1) Changes in resource allocations

   An IT program may need the change of resource allocation, because divisions’ marginal utilities will be affected by the IT program. For example, the adoption of customer relationship management system may benefit the marketing division and reduce the needs for manpower. In another aspect, the division may need more input to train employees to use the new system. An IT program may also lead to more reusable and sharable resources. In this way, with the same amount of resources in the organization, the total available resources measured by summing up allocated to divisions will increase. This change is not costless. Extra managerial effort will be exerted and resource reallocation may also become necessary.

2) Changes in designated yields that require more efforts from some divisions.

   An IT program will benefit the organization with a higher profit from lower costs and better productivity, which also changes the yield designation to each divisions. As a result of the
fact, how to encourage affected divisions to exert more effort is key because yields are the consequence of the efforts by divisions given certain levels of resources.

3) Changes in divisional effort deployment.

A side-effect effect of the above, changed resources and designated yields could cause divisions to adjust their efforts and conduct resource/yield exchanges to maximize their utility. The effort adjustment includes two aspects: the change of effort deployment to different yields, and the change of total effort exerted. Increasing effort does not mean that the division’s utility will be reduced because of higher costs by more efforts. When benefits from yield increase exceeds the extra cost of efforts, the division will be better off. In the same sense, reducing effort does not indicate higher utility to a division.

The above impacts finally result in the changes of cost structure at both divisional and organizational levels. A summary of the costs and benefits from an IT program can be found in the research by Malan and Wentzel (1993) specifically in the software reuse programs. Since an IT program is a multi-stage process – the effort invested in certain stage will benefit divisions in the later stages, the initial costs in setting up an IT program mechanism could be much higher, and the increased costs could mainly incur to some divisions, though other divisions could reduce the costs. Therefore, in analyzing divisions’ attitudes toward an innovative IT program, we need to examine the changes of costs with regard to resource, yields and efforts on a multi-stage basis.

3.2 Case study

The impacts of an IT program on TCNE vary from division to division depending on the boundaries of the program and the functionality of a division in the organization. To better
understand how the TCNE transitions with the effect of IT program adoption, let us examine closely the possible outcomes of innovative IT adoption in a multi-division organization, FEIC.

FEIC is a computing service center for the local government with 150 employees. In last 20 years FEIC has been operating IBM mainframes to provide database and data processing services. In addition, FEIC also provided technical supports to several governmental departments in office automation, including LAN set up and web-based application development. Recently FEIC has decided to replace all IBM mainframe computer systems with Dell PowerEdge servers. FEIC will adopt a 2-tier LAN structure. The first tier consists of the Dell servers connected with a Gigabit ATM switch via OC-12 fiber optic cable and the second tier connects all division-level LANs with 100Base-T Ethernet. The benefits to FEIC are obvious: better maintainancability, more reliability, lower electricity bill, cut-edge computer technology, and better connectivity to the government’s LAN system. The affected divisions in FEIC are: Data Procession Division (DPD), and Computer System Operation Division (CSOD). The two divisions have long been cooperating in data processing and software development. CSOD provides computing resource services and helps DPD in solving programming problem at system level, while DPD’s demand for technical support is the need to maintain a good team of system software programmers. The new IT program will definitely affect the cooperation between the two divisions.

The impacts of the above IT program adoption on FEIC will result in the following four possible outcomes with regard to the TCNE:

**Outcome 1**: The IT program is adopted without a reallocation of resources between DPD and CSOD. Both divisions set aside part of their resources to invest in an evolving organizational infrastructure. The adoption of the IT program is believed to deliver higher utility with fewer resources and less effort in the long run. More room is allowed for a new contract to exist between the two divisions.

**Outcome 2**: The IT program adoption in this case requires the reallocation of resources among divisions. This is mainly because the Dell PowerEdge running Window 2000 Server, Linux, or Free BSD operating systems are easier to maintain than IBM’s MVS/TSO and
VM/CMS operating systems. So, CSOD will have reduced workloads, while DPD will need to learn how to customize the servers for their applications because they are also providing the technical support to government web services. Therefore the adoption of the IT program is believed to bring about an increase in expected utility to DPD only if FEIC transfers some of system programmers in CSOD to DPD to compensate for their extra effort in coping with new yield levels and achieve the same level of expected utility as before. The key for the success of the IT program adoption is how to work out a feasible manpower reallocation plan.

Outcome 3: In this case at least one division is worse off with the adoption of the IT program because of extra effort for an IT program even though resources will be reallocated. For example, previously implemented databases in IBM IMS must be ported to ORACLE databases – a leap from the hierarchical database to the relational database. This turns out to be the major project for DPD before the system can be switched to the new computing platform. This results in a situation where there is no room for DPD and CSOD to reach a contract that can exchange resources and adjust efforts among the divisions and keep their own utilities no less than before. A typical solution is to increase the weights for evaluating the efforts for the new IT program and to count them more towards promotion or bonus. The incentive mechanism must be realigned in a way that would encourage DPD to exert more effort than before aiming at a higher expected utility.

Outcome 4: Under certain conditions, there could be no feasible incentive alignment plan for Outcome 3. In this case, the IT program is totally infeasible within the possible solutions by FEIC. In general situations, we anticipate that this would be the case when it is very costly for FEIC to make the transition from IBM mainframe to Dell PowerEdge servers, either
because of the gap between the two technologies is so wide and the two affected divisions are unable to handle it, or that the application software porting tasks for the new system are too time-consuming that adopting the IT program will not add significant extra value to FEIC if it will be delayed so much.

4. Summary and Conclusions

This paper conceived a general equilibrium model, TCNE, for studying organizational dynamics in innovative IT adoption. TCNE is derived from transaction cost economics and incentive mechanism design. The analysis of the model reveals that there are four different situations in an IT program adoption, three of which will result in a successful adoption of innovative IT programs and one represent the case where the adoption of an IT program is not feasible. Complementary to what has been proposed in the IT literature, the paper suggests that huge investment in resources are not always necessary for the success of reuse. By conceiving a feasible incentive alignment an organization will not only make a difficult an IT program scheme feasible, but also improve the outcome of the an IT program adoption that has been acceptable to all divisions.
References:


