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A game theoretic analysis of the conditions of knowledge transfer by new employees in companies*

Abstract

The availability of knowledge is an essential factor for an economy in global competition. Companies realise innovations by creating and implementing new knowledge. Sources of innovative ideas are partners in the production network but also new employees coming from another company or academia. Based on a model by HECKATHORN (1996) the conditions of efficient knowledge transfer in a team are analysed. Offering knowledge to a colleague can not be controlled directly by the company due to information asymmetries. Thus the management has to provide incentives which motivate the employees to act in favour of the company by providing their knowledge to the rest of the team and likewise to learn from colleagues. The game theoretic analysis aims at investigating how to arrange these incentives efficiently. Several factors are relevant, especially the individual costs of participating in the transfer. These consist mainly of the existing absorptive capacity and the working atmosphere. The model is a 2x2 game but is at least partly generalised on more players. The relevance of the adequate team size is shown: more developers may increase the total profit of an innovation (before paying the involved people) but when additional wages are paid to each person a greater team decreases the remaining company profit. A further result is that depending on the cost structure perfect knowledge transfer is not always best for the profit of the company. These formal results are consistent with empirical studies to the absorptive capacity and the working atmosphere.

JEL classifications: C72, D83, O31

Keywords: Knowledge Transfer, Innovation, Game Theory, Absorptive Capacity

Zusammenfassung

Die Verfügbarkeit von Wissen und die Fähigkeit zur schnellen Anwendung von wissenschaftlichen Neuerungen stellen heute einen zentralen Erfolgsfaktor von Volkswirtschaften dar. Unternehmen machen mit Wissensgenerierung und –umsetzung Innovatio-

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nen. Anregungen dazu kommen von Partnern im Produktionsnetzwerk, aber auch von neuen Mitarbeitern, die aus der Wissenschaft oder einem anderen Unternehmen in das Unternehmen kommen. Auf einem Modell von HECKATHORN (1996) basierend werden die Bedingungen effizienten Wissenstransfers in einem Team untersucht. Da Wissensweitergabe aufgrung von Informationsasymmetrien nicht kontrolliert werden kann, muß das Unternehmen entsprechende Anreize setzen. Diese lassen sich spieltheoretisch ermitteln. Mehrere Faktoren spielen eine Rolle, besonders wichtig sind die Kosten des einzelnen, die ihm bei der Teilnahme am Wissenstransfer entstehen. Das Absorptionsvermögen und die Arbeitsatmosphäre bestimmen die Kosten in erster Linie. Das Modell ist ein 2x2-Spiel, das anschließend teilweise auf mehrere Spieler verallgemeinert wird. Die Relevanz der Teamgröße wird gezeigt und das vollständiger Wissenstransfer bei hohen individuellen Kosten nicht unbedingt gewinnmaximierend für das Unternehmen ist. Diese formalen Ergebnisse unterstützen vorhandene empirische zu Absortionsvermögen und Arbeitsatmosphäre.

Wissenstransfer, Innovation, Spieltheorie, Absorptionsvermögen

1. Introduction

The availability of knowledge and the ability to implement new knowledge into products and processes is essential for an economy to compete successfully in global markets.[1] The crucial part in innovation is usually attributed to companies. They exploit their existing knowledge and assimilate new findings from external sources. The implementation of new knowledge strengthens the position of the innovative company in its industry as well as the economy as a whole in global competition. An important source for innovations are suggestions of incumbent employees and partners in the production network (e.g. suppliers and customers) as well as the engagement of highly qualified people. They may have worked in another company before or, if the company is part of a multinational enterprise, may come from another subsidiary. A further source is a scientist leaving academia to work in the industry, which is a significant transfer channel with an even increasing importance for CZARNITZKI et al. (2000, p. 18). The essential point is that the new employee has new knowledge, which is not yet available in the company and rarely or not available anywhere else. COHEN and LEVINTHAL (1990) argue that a firm's ability to exploit external knowledge is a critical component of innovative capabilities (p. 128). If the knowledge is transferred and implemented – thus becoming an innovation –, it is possible to make additional profits by selling a new useful product to customers or to get a more competitive position in the industry by reducing process costs.[2]

This paper analyses the conditions of such knowledge transfer and the incentives a company can offer to influence knowledge transfer and to optimise profits gained by innovations due to sufficient transfer. Therefore a game theoretic model is developed on the basis of a model by HECKATHORN (1996). The new model shows the relevance of additional rewards for the employees engaged in the innovation process, the size of the team, and, most importantly, the individual costs of participating in knowledge transfer. These costs consist mainly of the effort to understand (or in the case of providing the knowledge: to explain) the new information, to connect it with existing knowledge and to apply it. COHEN and LEVINTHAL introduced the concept of absorptive capacity to explain how a person or a team is able to learn something from an external source. The

1 The European Council stated in March 2000 in the Lisbon Strategy that the aim for the EU is "*to become the most competitive and dynamic knowledge-based economy in the world, capable of sustainable economic growth with more and better jobs and greater social cohesion*". The importance of knowledge, and innovations resulting from it, for economic growth is not only an assumption of policy, but also a fact for authors like e.g. DAVID and FORAY (1995), AGRAWAL (2001) and EGELN, GOTTSCHALK et al. (2003).

2 The assumption that new knowledge leads to innovations is used here as it is common in innovation literature. Of course a failure is possible even with great effort to implement new knowledge. In this paper the success of an innovation generated by knowledge transfer is assumed, because otherwise the company cannot set incentives which are part of the profit made with an innovation.

ability to exploit external knowledge is mainly a function of the level of existing related knowledge and consists of the competence "to recognise the value of new information, assimilate it, and apply it to commercial ends" (p. 128). The idea behind this is that the more you know the better you are able to learn or adopt something new.

Literature review

Several authors studied the importance of the absorptive capacity empirically. LANE et al. (2001) analyse international joint ventures and demonstrate a positive association between knowledge from foreign parents and the joint venture's performance. The level of competence in training and personnel development improves performance as well. MINBAEVA et al. (2003) divide absorptive capability into the ability and the motivation to learn. They show empirically that both these factors enhance knowledge transfer. GUPTA and GOVINDARAJAN (2000) find for multinational corporation subsidiaries a positive relationship between absorptive capacity (measured by overlapping know-how) and knowledge inflows. Performance-based payment as a motivation to transfer also influences knowledge inflows positively. A positive influence of monetary incentives on working effort – even in situations with information asymmetries – was found long before e. g. by MALCOMSON (1984).

Closely connected with the concept of absorptive capacity is the phenomena of tacit knowledge first mentioned by POLANYI (1966). Tacit knowledge is partly or wholly inexplicable and can only be communicated by direct involvement of the knowledge provider or gained by personal experience. For efficient knowledge transfer it is necessary that both tacit and explicit knowledge are transferred at the same time. Therefore, personal interaction is crucial. NELSON and WINTER (1982) state that transferring tacit knowledge may be more complex for different reasons, especially the teaching of skills requires a higher time-rate of information transfer and the coherence of the knowledge structure makes the components useless when neglecting the whole. DHANARAJ et al. (2004) show a direct impact of tacit knowledge on explicit knowledge. Explicit knowledge in turn has a positive impact on performance. They cannot show this directly for tacit knowledge, but SUBRAMANIAM and VENKATRAMAN (2001) do. They analysed product innovations and found that the ability to transfer and use tacit knowledge significantly influences the transnational product development capabilities. NONAKA and TAKEUCHI (1995) hold that at least half of all knowledge is implicit and for transferring it, employees have to work closely together and trust each other. Thus the working atmosphere influences knowledge transfer. Finally BUCKLEY and CARTER (2004) analyse amongst other things the influence of the working atmosphere on knowledge transfer in multinational enterprises and state that "[a] culture of mutual trust is probably the most important requirement for the promotion of knowledge exchange" (p. 380).

In this paper, the issue of knowledge transfer is assessed from the point of view of the incentive structure for knowledge providing (and receiving) employees. This incentive structure is treated at the firm level, i. e. within the power of individual firms to determine the optimal use of knowledge potentials and to earn additional profits through innovations. Following the research on absorptive capacity it is assumed that the individual costs of participating in the transfer of knowledge are determined to a large extent by absorptive capacity and working atmosphere. The relation between the costs of knowledge transfer and the rewards the employees earn by the implementation of an innovation determine the effort of the employees in knowledge transfer.

The model is a 2x2 game but is at least partly generalised on more players in order to show the relevance of the team size. In the model, a researcher or developer with distinct new knowledge comes into a company, a common situation. Offering knowledge to a colleague can not be controlled directly by the company due to information asymmetries. Thus the management has to provide incentives which motivate the employees to act in favour of the company and by providing their knowledge to the rest of the team and likewise to learn from colleagues. The game theoretic analysis aims at investigating how to arrange these incentives efficiently and what conditions influence knowledge transfer.

The paper has the following structure: In the second section the model of Heckathorn is presented and how it can be adapted to the problem. It s shown how a company can optimise knowledge transfer. In the third section a partly generalisation on more than two players is develoled and the fourth section concludes.

2. The game theoretic model

HECKATHORN (1996) developed a model about "The dynamics and dilemmas of collective action", where he analyses how a society or any other group produces a public commodity. This model is described shortly and isthen adapted to the problem of knowledge transfer.

Heckathorn defines the production function of the public commodity as

$$L = 1 - \left(\frac{d}{n}\right)^{F} \tag{1}$$

L is the level of production (that can reach 100 per cent at maximum), d the numbers of defectors and n the number of players. F defines the shape of the production function. F is always greater than zero, i. e. the production function is increasing (more input = more output). If nobody cooperates, d = n and no commodity is produced. For d = 0 the production is at maximum because everybody cooperates.

The payoff function for each person is

$$U = V \cdot L - c, \tag{2}$$

with V as the value of the whole production of the public commodity and c as the individual costs of cooperation for each person. The costs c depend on working conditions[3], but not on the number of cooperating people.

For simplicity a symmetrical 2×2 game is assumed, i. e. two players with two possibilities to act (to cooperate or not). In a one-time game the row player has the following payoffs (the values for the column player are analogue):

Figure 1:
Payoff matrix of player 1

		Player 2	
		cooperating	non-cooperating
Player 1	cooperating	V-c A	C V(1-0,5^F)-c
	non-cooperating	V(1-0,5^F) B	D 0

Source: Heckathorn, 1996, p. 256, table 1.

3 The determinants of the working conditions are explained in more detail in the following section.

Depending on the specification of the model determinants five situations can arise, that differ in the height of the payoffs and therefore the preferred order of the different options of action.

- Privileged Game: the dominant strategy is to cooperate, what is individually and socially the best. Thus there is no problem as long as the players do not want to harm each other.
- Prisoner's Dilemma: both players would profit the most when cooperating, but when they individually optimise their behaviour both will defect and the payoff will be at minimum. Defecting is a dominant strategy.
- Chicken Game: for each player it would be best if only the other one cooperates, but if the other one defects it is still better to cooperate than to defect as well.
- Assurance Game: parallel behaviour is better than unilateral cooperation. Each player does what he thinks the other one does.
- Altruist's Dilemma: in fact there is no "dilemma", because it is individually and socially best not to cooperate. Only if the players are altruists and think they help the other person when cooperating an inefficient solution arises. In sociology this might be a dilemma but in economics this situation can not occur under the assumption of rational acting people and the assumption of effort necessary for knowledge transfer (see below).

F shapes the production function. If it is greater than 1, returns to scale are decreasing, between 0 and 1 there are economies of scale (increasing returns to scale). In the first case every additional cooperating person adds less to the level of production. In the case of economies of scale every additional person adds more to the production. In this case only a high degree of cooperation will lead to a reasonable level of production.

Adapting the model for knowledge transfer

The model becomes useful for the analysis described the situation of a new employee coming into a team, if a company is viewed as an economy with N employees and L as a new product or process that leads to additional sales. It can only be produced with implementing the knowledge from the new team member. The additional effort made by the employees for transferring knowledge is c. They get additional utility by participating in the profit made with the new product. Let this additional wage be V in case of full production and respectively lower if the level of production is less than one hundred per cent. The overall profit P_{whole} is divided into a part the company gets P_{com} and a part for the developers of the invention P_{emp}. Each developer earns the same part of P_{emp}, so $V = \frac{1}{n} P_{emp}$. It is assumed that knowledge transfer only occurs with some effort. This assumption was also made by BUCKLEY and CARTER (2004). The new employee needs to explain and to show his special knowledge, the effort of the existing colleagues is to understand and learn what is shown to them. Both have to combine old and new knowledge to get a new combination that leads to the innovation. The effort is influenced by longer working time as well as the absorptive capacity and the working atmosphere. As described before, the absorptive capacity determines the ability to learn and the working atmosphere influences strongly the motivation to learn and teach.

Two restrictive assumptions must be made compared to the original model. The Altruist's Dilemma will not arise. It implies higher individual costs than additional wage. According to the rationale of the model, I assume that rationally acting employee would not cooperate in this case, because it means that making an effort to transfer knowledge leads to a successful innovation but the company does not pay the employees for it. The other assumption is that the production function of innovative products has decreasing returns to scale. If one thinks of the production function as proportional to the cumulative knowledge of the employees, the assumption is feasible. There is some basic knowledge everybody has. Then everyone has additional knowledge, part of it may be already available by someone else. Thus the probability that the knowledge of a new team member is already known increases with the number of group members and every new person accounts for a smaller part of the cumulative knowledge. The redundant knowledge is necessary for the communication within the team but it decreases productivity. New insights may be generated by group work but this effect is smaller than the decreasing productivity caused by redundant knowledge.

If parallel cooperation is called A (as in figure 1), cooperation only by player 1 C, cooperation only by the second player B, and parallel non-cooperation D the following situations occur (illustrated in figure 2):

Privileged Game (PG)

The payoff of player 1 is by definition of the PG ranked A > B and C > D.

$$V - c > V(1-0.5^F) \text{ and} \tag{3}$$

$$V(1-0.5^F) - c > 0 \tag{4}$$

This results in

$$c < V \cdot 0.5^F \Leftrightarrow \frac{c}{V} < 0.5^F \text{ and} \tag{5}$$

$$V(1-0.5^F) > c \Leftrightarrow \frac{c}{V} < 1-0.5^F. \tag{6}$$

The PG emerges if the rate of additional costs to additional wage is smaller than the two thresholds of (5) and (6). Which one is relevant in a special case depends on the shape of the production function F. The rate of c to V can not be greater than 0.5 in the Privileged Game.

Prisoner's Dilemma (PD)

The payoff of player 1 is by definition of the PD ranked B > A > D > C.

$$V(1-0.5^F) > V - c > 0 > V(1-0.5^F) - c \tag{7}$$

This results in

$$V > c\,, \tag{8}$$

$$V(1-0.5^F) < c \;\Leftrightarrow\; \frac{c}{V} > 1-0.5^F \;\text{ and} \tag{9}$$

$$V \cdot 0.5^F < c \;\Leftrightarrow\; \frac{c}{V} > 0.5^F\,. \tag{10}$$

The same two thresholds as in the PG apply for the Prisoner's Dilemma, now as the lower limits. The PD emerges with a high rate of additional costs to additional wage, but still the additional wage is greater than the individual costs.

Chicken Game (CG)

The payoff of player 1 is by definition of the CG ranked B > A and C > D.

$$V(1-0.5^F) > V - c \;\;\text{ and} \tag{11}$$

$$V(1-0.5^F) - c > 0 \tag{12}$$

This results in

$$V(1-0.5^F) > V - c \;\Leftrightarrow\; \frac{c}{V} > 0.5^F \;\text{ and} \tag{13}$$

$$V(1-0.5^F) > c \;\Leftrightarrow\; \frac{c}{V} < 1-0.5^F\,. \tag{14}$$

The Chicken Game emerges if the rate of additional costs to additional wage lies in between certain limits. This implies decreasing returns to scale, i. e. an F > 1. Compared with the Prisoner's Dilemma, the rate of additional costs to additional wage is lower, but it is still greater than in the Privileged Game.

Assurance Game (AG)

The payoff of player 1 is by definition of the AG ranked A > D > C and A > B.

$$V - c > 0 > V(1 - 0.5^F) - c \text{ and} \tag{15}$$

$$V - c > V(1 - 0.5^F) \tag{16}$$

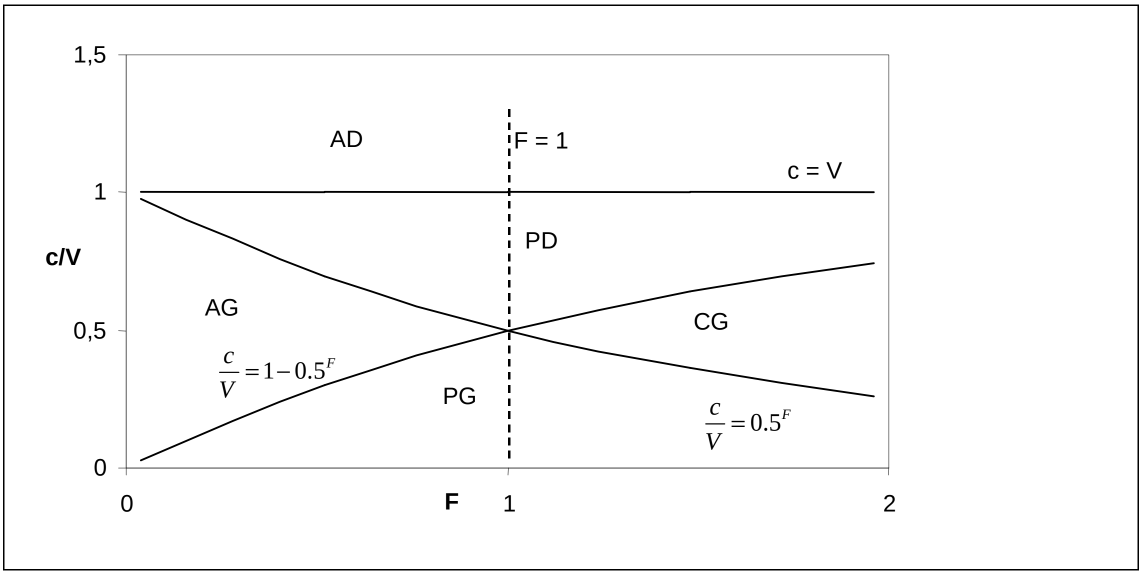
This results in

$$V > c, \tag{17}$$

$$c > V(1 - 0.5^F) \Leftrightarrow \frac{c}{V} > 1 - 0.5^F \text{ and} \tag{18}$$

$$c < V \cdot 0.5^F \Leftrightarrow \frac{c}{V} < 0.5^F. \tag{19}$$

Figure 2:
Illustration of the five situations dependent on additional individual costs c, additional wage V and the shape of the production function F



AD = Altruist's Dilemma, PD = Prisoner's Dilemma, AG = Assurance Game, CG = Chicken Game, PG = Privileged Game (a similar graphic exists at HECKATHORN, 1996, p. 257)

Again the rate of additional costs to additional wage lies in between certain limits. This time a production function with increasing returns to scale is implied, i. e. F < 1. This was excluded by the assumptions in the beginning and no Assurance Game can arise. Equally the Altruist's Dilemma can not arise.

The lines in figure 2 represent the borders between the presented situations. The dashed line divides increasing from decreasing returns to scale and the horizontal line c = V shows the upper limit of the rate of additional costs to additional wage. Thus the relevant part of the graphic is the rectangle in the lower right. With a decreasing ratio of c to V it is possible to come from the Prisoner's Dilemma through the Chicken Game to the Privileged Game where knowledge transfer is complete.

Optimisation in the company's perspective

In order to optimise knowledge transfer from highly qualified new employees to other team members as a basis for economic success the rate of additional costs to additional wage must be low. Either the costs are low or the wage compensation is high. As mentioned in the introduction the stock of knowledge affects strongly the absorptive capacity, i. e. the ability to understand and implement something new increases with existing knowledge. Furthermore a good working atmosphere as well decreases the costs of cooperation, with mutual trust the employees feel less effort to exchange knowledge.[4]

By means of the HECKATHORN model the relevant area for full knowledge transfer was found. The area is defined by the two inequations F > 1 and $\frac{c}{V} < 0,5^F$. It is possible to determine an optimal behaviour of the company. If c is fixed, the company should set the additional wage V as small as possible to still satisfy the inequation. Let us take the assumption that a player cooperates when the utility of cooperation is equal to that of non-cooperation. Then V results in

$$V = \frac{c}{0.5^F} = c \cdot 2^F \qquad (20)$$

This additional wage is paid to both players. It is part of the overall profit P_{whole} the company will earn with the new product or process if every player would cooperate. The payment to the developers reduces P_{whole}. The company thus earns

$$P_{com} = P_{whole} - 2 \cdot c \cdot 2^F = P_{whole} - c \cdot 2^{F+1} \qquad (21)$$

Equation (21) shows that the employees' costs c reduce the profit of the company. Optimizing the income means reducing the additional costs of the employees as long as the

4 See *Buckley and Carter* (2004).

company increases the profit more than the cost reduction costs k. A given c represents the actual costs of knowledge transfer, determined by the qualification of the employees, the mutual trust and the efficiency of the organisational structures. If these costs are high, it will be easy to reduce them a little, for example by further education or confidence-building measures. If the costs are low already, more effort is necessary to reduces them further until y point where more reduction is not possible. So the function of k(c) is convex, and zero at the actual costs c_0.

The marginal income of the company is

$$P_{com}{}'(c) = -2^{F+1} \tag{22}$$

A reduction of c by one entity increases P_{com} by 2^{F+1} entities. As long as k < 2^{F+1}, a reduction of c is rational. The optimum is reached at k = 2^{F+1}. Then the profit of the company is at maximum and the knowledge transfer is efficient.

3. More Players

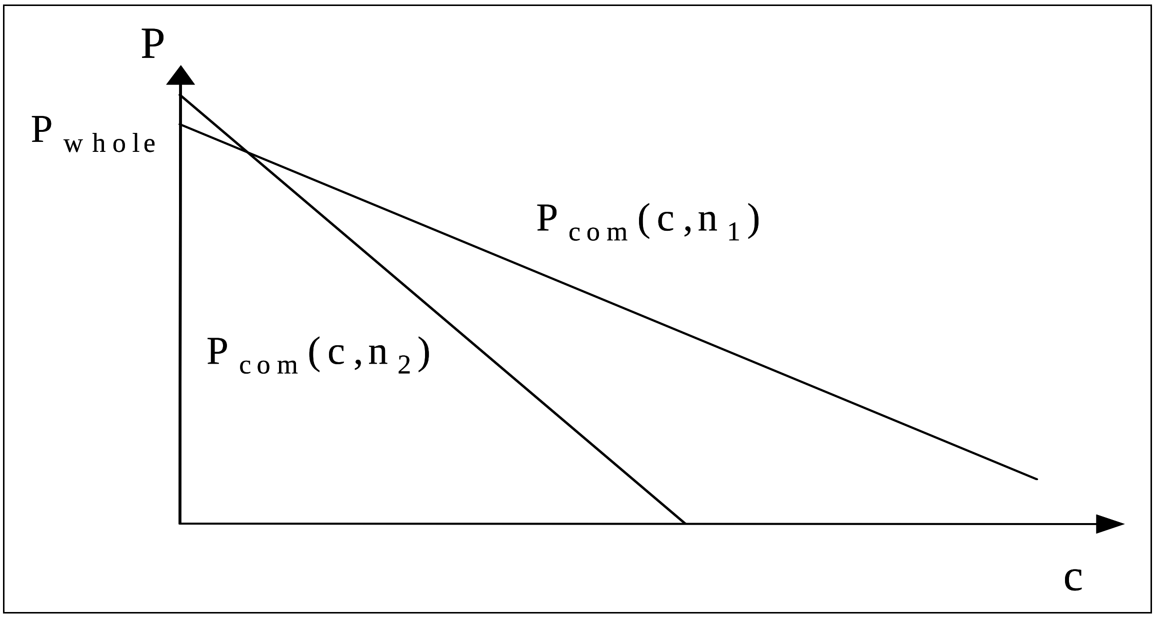
An innovation usually can be attributed to a team, but not to individual members of that team. Such a research team consists of a certainly limited number of developers, because a special question is never analysed by a large group. Large groups have smaller entities responsible for a certain task. And their work can be distinguished from that of others. Thus these smaller entities are the relevant team size for the transfer problem described above. For a group of about five members the assumption of a symmetrical game can still be uphold.

The border between the Privileged Game and the Chicken Dilemma was $\frac{c}{V} = 0,5^F$ or more generally $\frac{c}{V} = \left(\frac{1}{n}\right)^F \Leftrightarrow V = cn^F$, because it is the border between no defector and one defector. The company's profit function changes to

$$P_{com} = P_{whole} - n \cdot cn^F = P_{whole} - cn^{F+1} \tag{23}$$

P_{whole} is not independent of the team size n: It will increase concavely up to an upper limit and can decrease again when the coordination of the team becomes difficult and information flows become complex due to the number of team members.

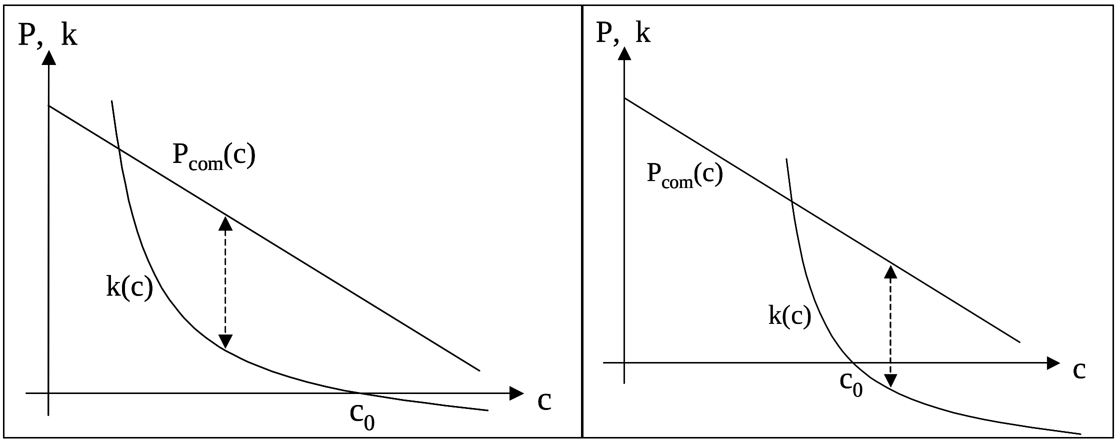
Figure 3:
Profit function of the company for two different n with $n_1 < n_2$.



In order to realise the same profit with a larger team the company has to decrease the individual costs of the team members. As mentioned above decreasing the additional costs creates new costs k. The smaller c is already, the higher k will be. As long as c is high, it is not difficult to decrease it, and it could even occur that it is possible to save money by increasing c. Thus $\frac{dk(c)}{dc} < 0$ and $\frac{d^2k(c)}{dc^2} > 0$ and if c0 denotes the current situation, $k(c_0) = 0$. The profit for the company including the consideration of reducing the individual costs c is

$$P_{com}^{k}(c) = P_{com}(c) - k(c) = P_{whole} - cn^{F+1} - k(c)\,. \tag{24}$$

Figure 4:
Illustration of company profit P_{com} and costs k needed to change c.



Given costs are c_0. The dashed arrow shows the profit of the company when considering a shift of c. Maximum profit is realised for the company where the difference between P_{com} and k is largest. In the right situation this optimum is reached by increasing c.

The optimal costs c for the company are reached, when $\frac{dP_{com}}{dc} = \frac{dk(c)}{dc} = -n^{F+1}$.

It is also possible that a situation arises where the costs are so high, that there is no positive difference between P_{com} and k (see fig. 5). In this case the Privileged Game is no longer the best game. If fewer team members cooperate, P_{whole} decreases – the production level is not at 100 per cent –, but so does V. Let not the border between no and one defector be relevant, but the one between one and two defectors, i. e. a kind of chicken game (CG) is best for the company's profit. For every person – knowing that one will defect – it is better to cooperate, as long as

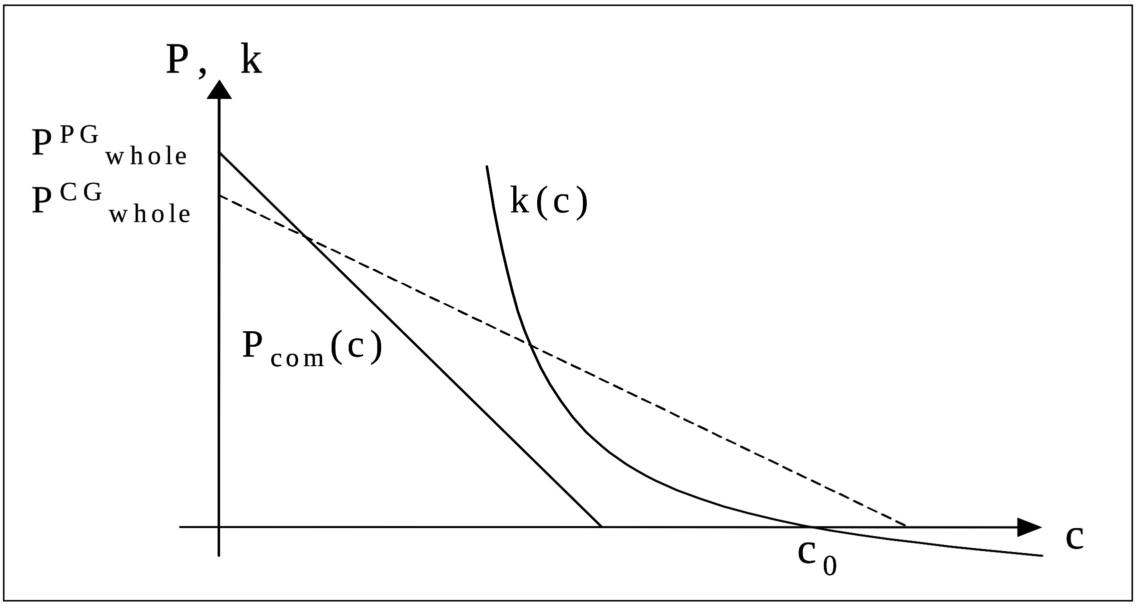
$$V(1 - \left(\frac{1}{n}\right)^{F}) - c > V(1 - \left(\frac{2}{n}\right)^{F})\,. \tag{25}$$

The relevant limit than will be

$$V^{CG} = c\frac{n^F}{2^F - 1} \tag{26}$$

which is smaller than V in the case of the Privileged Game.

Figure 5:
The situation that a Chicken Dilemma (CD) is better for knowledge transfer than the Privileged Game (PG) – from the company's perspective.



These considerations show the relevance of the team size and the structure of the costs each employee faces for knowledge transfer:

- If the individual costs of knowledge transfer are high or a reduction is expensive, there will be no complete knowledge transfer.
- If the size of the team increases, the profit of the company decreases and it can occur that knowledge transfer is no perfect, when the company optimises profit.

There is an optimal development team size for the company, which is determined by different factors: on the one hand P_{whole} that increases with the number of team members as long as n is small. On the other hand the increasing (in n) wage payments that in turn depend on the costs c. The company has to decide about this optimal team size and wether it is efficient to aim at complete knowledge transfer. The better an innovation can be attributed to the relevant persons, the higher the profit will be because in the optimum nobody is paid who has not contributed to the innovation.

4. Conclusions

The analysis shows how a company earns the optimal profit from a new employee who has knowledge that is not yet established in the company under the assumption that broadening the knowledge base leads to innovations. The incentives were divided in monetary incentives modelled as the additional wage and motivational incentives included in the costs of effort. It was shown that efficient knowledge transfer only occurs at a low rate of additional costs to additional wages. The individual costs thereby consist mainly of the absorptive capacity and the working atmosphere. If the costs of cooperation are to high, complete knowledge transfer will not occur. The importance of the absorptive capacity for knowledge transfer found empirically by MINBAEVA et al. could be confirmed formally. The same holds true for the working atmosphere as it was found by BUCKLEY and CARTER. Furthermore the size of the team involved in producing an innovation as a highly relevant factor was identified. The partly generalisation of the model on more players shows the relevance of the adequate team size. More developers may increase the total profit of an innovation (before paying the involved people) but when additional wages are paid to each person a greater team decreases the remaining company profit.

Of course there are some limitations of the model presented. (i) It applies only for the assumption of rationally acting people. (ii) There is uncertainty about the profit of an innovation, in the worst case an innovation could fail totally. (iii) The model cannot be wholly generalised on every number of players because of complexity but this limitation holds for all game theoretic models.

Nevertheless I hope to contribute to the research about knowledge transfer and the importance of absorptive capacity. Further research could e. g. analyse the knowledge gap between the new employee and the incumbent and if it depends on the origin of the employee – there might be a greater distance between incumbent employees and scientists compared with employees coming from another company.

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