Chapter 2
Evolution Mechanism of Scale Invariant Knowledge Network Influenced by Exogenous Factors

Ziyang Geng, Li Zhang and Xin Gu

Abstract Scale invariant knowledge network is always not formed for some specific objectives. Exogenous factors can not make the knowledge state changing synchronous through the existence purpose of knowledge network. Its influence will appear gradually depending on network nodes' asynchronous cognitive through more complex channels. Based on the power architecture reflecting how exogenous factors promote knowledge network's evolution, the function analytic solution has been given according to mathematical model considering both of individual communication channel and group spreading channel. Further more, computer simulation about how power architecture features affect knowledge network's evolution has been given too.

Keywords Exogenous influence · Scale invariant · Knowledge network's evolution · Dual channel spreading

2.1 Introduction

There is no uniform definition of knowledge networks by now. In the earliest definition given by Bechmann [1], knowledge network was described as an institution or activity for knowledge creation and spreading. Andreas pointed out that knowledge network is knowledge's creation and spreading on all the levels of individuals, groups, within organizations and between organizations [5]. Such knowledge

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network (we call it the first type network) is formed for specific purpose. Apart from the first type network, another type knowledge network is loose carrier for knowledge flowing. This type network (we call it the second type network) not only has no specific purpose and clear boundary but also has changeable structure. NSF defines knowledge network to be a social network which is an international communicating network providing knowledge and information and covering different languages and disciplines.

Besides above two types, the third view is knowledge network is not formed for specific purpose and is scale stable relatively which means the collection of network nodes is stable relatively. We call this type network the third type network. Kobayashi defined knowledge network is some kind of system formed by collection of nodes and relationships between them. He made the nodes stand for the discrete situation of human settlements which have concentrate knowledge production capacity and permanent activity ability [2].

Researches about knowledge network cover fields of knowledge network's formation, performance, coordination, evolution etc. Relatively speaking, researches about knowledge network evolution are less than them in other fields. Ritter et al thought enterprise knowledge network has features of dynamic and embeddedness and relationships between nodes are based on the combination of autonomy and interdependence. He believed the communication rules will promote or control knowledge flowing and then influence enterprise ability's developing [3]. Cowan et al studied the dynamic process of knowledge evolution in network type industry. He not only compared the influences of transferring knowledge random and under normal system to knowledge network evolution but also made simulation for corresponding models [4]. The researches of knowledge network evolution are mainly about the first type network while little about other two types.

The third type knowledge network can be seen as transition type between the first type and the second type. It will be helpful for research of the second type network's evolution to find out some rules of the third type network's evolution.

The main feature of the third type knowledge network is stable scale that means the nodes collection is relative stable. But this type network is not formed for specific purpose, the node relationship structure will change dynamic and the changing regularity is weak. Taking into account of such situation, this article will measure the degree of knowledge network evolution based on the degree of knowledge change.

The direct reason of knowledge change is demand for new knowledge while the more deep reason is the nodes' adaptive behavior for external environment changes. When one external factor appears, its influence can not push all the network nodes change their knowledge status synchronous because there is no specific purpose relating to knowledge network's existing. So some more complex channels will be useful to make nodes to be cognitive of the external factor and then to change their knowledge status. This article will discuss the evolution mechanism considering these complex channels.

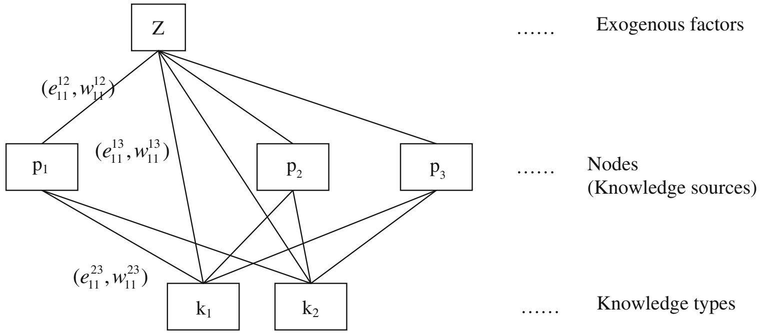


Fig. 2.1 Exogenous factor's power structure for knowledge network evolution

2.2 Exogenous Factor's Power Structure and Effect Way

2.2.1 Power Structure

We make Z stands for an external factor and make $I = I(P, K, E, W)$ stands for a scale invariant knowledge network (for short as knowledge network). $P = (p_1, p_2, \cdots)$ is the node collection and $K = (k_1, k_2, \cdots)$ is the knowledge type collection. $E = (e_1, e_2, \cdots)$ stands for the undirected edges between P and K. $W = (w_1, w_2, \cdots)$ stands for the weights of $E = (e_1, e_2, \cdots)$. Edges mean there are relationships between nodes and knowledge types. Weights mean the degrees of nodes' knowledge types and $w_x \in [0, 1], x = 1, 2, \cdots$. If one node does not have one specific knowledge type, the weight of the corresponding edge is zero. Z and $I = I(P, K, E, W)$ form the power structure of knowledge network evolution commonly (Fig. 2.1).

We denote:

1. the edges and weights between Z and nodes in Fig. 2.1 as $E^{12} = \left(e_{11}^{12}, e_{12}^{12}, \cdots\right)$ and $W^{12} = \left(w_{11}^{12}, w_{12}^{12}, \cdots\right)$.
2. the edges and weights between Z and knowledge types as $E^{13} = \left(e_{11}^{13}, e_{12}^{13}, \cdots\right)$ and $W^{13} = \left(w_{11}^{13}, w_{12}^{13}, \cdots\right)$ with $w_y^{12} \in [0, 1], y = 1, 2, \cdots$ and $w_z^{13} \in [0, 1], z = 1, 2, \cdots$. The edges and weights between nodes and knowledge types are E and W. Here we denote them as $E = E^{23} = \left(e_{11}^{23}, e_{12}^{23}, \cdots\right)$ and $W = W^{23} = \left(w_{11}^{23}, w_{12}^{23}, \cdots\right)$.

There are three situations for the meanings of edges and weights in Fig. 2.1.

1. E^{12} means nodes can perceive exogenous factors and its weights stand for nodes' sensitive degrees. One weight is bigger, the understanding of corresponding exogenous factor is better. On the contrary, one weight is smaller, the understanding of corresponding exogenous factor is worse.

2. E^{13} means current knowledge types have probability to change their status influenced by exogenous factor and its weights stand for the size of possible space for change. The bigger one weight is, the larger space size corresponding knowledge type will have while it is easier influenced by exogenous factor. On the contrary, one weight is smaller, the space size is smaller while knowledge type is harder to change its status.
3. E^{23} means knowledge types nodes have and its weights stand for the types' degrees. One weight is bigger, the corresponding degree is higher. One weight is smaller, the corresponding degree is lower.

Because the scale is invariant, the final result of power from exogenous factor will reflect in changes of knowledge types. In each triangle formed with three nodes and three edges both of them are picked from three node levels in Fig. 2.1 randomly, the knowledge network's change will occurs in such a small environment only when every weight of the three edges is not zero. We will call triangles every weight is nonzero to be effective triangles and triangles have edge weight is zero to be null triangles.

For each effective triangle, actual knowledge type revise action is always risk even the node is sensitive or the changing space is large. So some nodes maybe will not change their knowledge types under exogenous factor's influence. For those nodes going to change, the changing times are not synchronous too.

The process of knowledge types' changing is always a gradual process from point break to surface break: there are must some nodes of foresight will react to exogenous factor with changing their knowledge types and their neighbors will act like them next thus the exogenous factor's influence will gradually expand. This process can be seen as predictable overall and there are only positive revise because of knowledge's indelible feature.

Further more, we consider the concrete ways in which effective triangles' revise their knowledge types. The revises may happen in predictable generating ways or in unpredictable emerging ways. A concrete way will depend on knowledge type's technical property, node's investment policy, cooperation process and mechanism of knowledge creation, external environment pressure etc. So a concrete way relates not only to effective triangle's small environment but also external large environment with complex domain features.

According to above analysis, the power structure in Fig. 2.1 can be transferred to Fig. 2.2.

In Fig. 2.2, each edge of every effective triangle has nonzero weight and the relationships between these triangles are the relationships between knowledge sources in them. We denote the collection of edges as $E = \left(e_1^1, e_1^2, e_1^3, e_2^1, e_2^2, e_2^3, \cdots\right)$ and the collection of weights as $W = \left(w_1^1, w_1^2, w_1^3, w_2^1, w_2^2, w_2^3, \cdots\right)$.

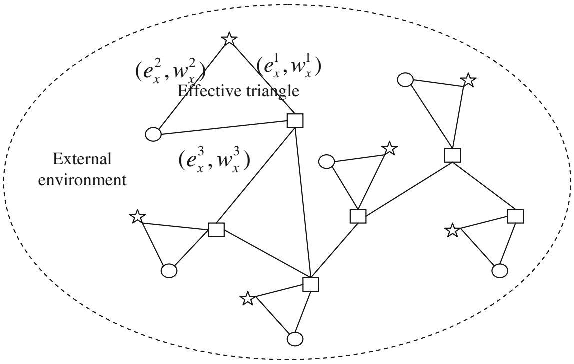


Fig. 2.2 Exogenous factor's power structure based on effective triangle. *Note Star* stands for exogenous factor, *square* stands for node (knowledge source), *circle* stands for knowledge type

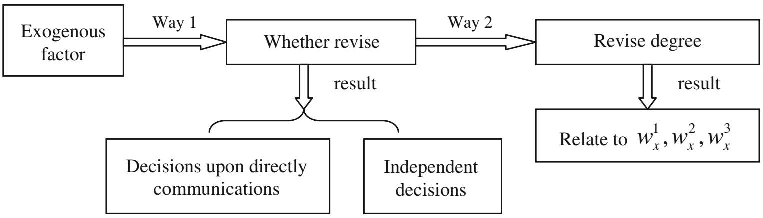


Fig. 2.3 Effect way and result of exogenous factor's power

2.2.2 *Effecting Way*

There are two effecting ways of exogenous factor (Fig. 2.3). The first is to influence knowledge sources' decision about whether revise knowledge types or not. The second is to influence the degree of revise.

The result of the first way has two situations. One is exogenous factor expands its influence through direct communication between knowledge sources and then the proportion of active sources bigger and bigger. Another one is knowledge sources decide their revise actions independently.

The result of the second way relates not only w_x^1 and w_x^2 but also w_x^3.

Among these two ways, the second way is follow-up of the first way and its effective range will not exceed the first way's range too. Specifically, the knowledge type's revise degree belongs to the effective triangle the first way point out. So the first way is the main trail for exogenous factor's influence.

For the two results of the first way, it is the main one that expanding influences through direct communication. This is common sense that brilliant organizations or persons are always minimum ones. So the second result of the first way will be seen as exception of the first result.

2.3 Model of Power Mechanism

There is a situation in epidemics spreading that virus spreads through direct touching and infected person can not be cured, such as HIV. For this situation, SI model based on famous SIR model can be used to explain its spreading mechanism. The exogenous factor's influence spreading is similar to such epidemics' spreading while has its particularity. The similar respect is knowledge's indelible feature makes the result of knowledge revise is irreversible. The particularity is one knowledge source's revise action will be known by others rapidly through highly developed knowledge communication channel and then the knowledge source's action decision will influenced not only by direct communication relationship between each other but also by the active atmosphere made by those sources who have done their revise decisions.

The spreading channel of exogenous factor's influence will be divided into two types. One is individual communication channel which means expanding through neighbor's communication, just like epidemics' spreading. Another one is group spreading channel which means knowledge source' cognition or judgment about exogenous factor's overall influence will promote its own probability of revise action.

It is possible that knowledge source will be "infected" while its neighbors are all "healthy". That is the group spreading channel might work without the individual communication channel. Just like independent infected case because of variation is ignored in research of epidemics spreading, we make hypothesis:

Hypothesis 1. when individual communication channel and group spreading channel are all effective, group spreading channel can only effect through individual communication channel.

We call a node of knowledge source who decide to revise its knowledge type to be excited state node and the other nodes to be unexcited state nodes. We use direct communication proportion δ to stands for the probability of an unexcited state node transfer into excited state in unit time when it only touches an excited state node. δ is a stable parameter. We use group spreading proportion δ' to stands for the probabilities of an unexcited state node transfer into excited state in unit time when both of the two spreading channel are all effective. δ' is unstable because the density $i(t)$ of excited state nodes is changing.

Hypothesis 2. when both of the two spreading channel are all effective, δ' will rise with the increase of $i(t)$ and

$$\delta' = \delta\varepsilon[1 + i_t], \tag{2.1}$$

δ is direct communication proportion. ε is group effect parameter which means the group atmosphere's influence result to δ.

In Eq. (2.1), there must be $\varepsilon \le \frac{1}{2\delta}$ because of $\delta' \le 1$.

Group atmosphere can make negative effect which means δ' could be smaller than δ. One reason for this situation may be the side effect of sentiment for new things. So the limit of ε depends on whether group negative effect or not.

If there is not negative effect, we will have, from $\delta' \ge \delta$.

If there is negative effect, we will have $\varepsilon \ge 0$ from $\delta' \ge 0$. So the range of ε are

$$\begin{cases} \frac{1}{1+i_0} \le \varepsilon \le \frac{1}{2\delta}, & \text{no negative effect} \\ 0 < \varepsilon \le \frac{1}{2\delta}, & \text{negative effect.} \end{cases} \tag{2.2}$$

The change rate π stands for revised knowledge type's average increase degree. Except the influence from external environment, δ' and π are also restricted by the specific environment in effective triangle. Such restriction reflects on the weights of effective triangle.

The probability will be higher only when knowledge source is sufficient cognitive of exogenous factor, the revise space is large enough and current knowledge foundation is better. The final revise degree is affected by all these three factors. The easier for spreading, the bigger π is. It is mean that the directions of influences on δ' and π are same.

Hypothesis 3. the changing directions of δ' and π are same and $\pi = \tau\delta'$. τ is synchronous parameter. We denote density of unexcited state node as $S(I)$. So we have $s(t) + i(t) = 1$. We denote ψ as the average degree of knowledge types before exogenous factor appearing and $\phi(t)$ as the function of average degree of knowledge type changing with time after exogenous factor appearing.

First of all, we build model referencing SI model for the situation only existing individual communication channel. We call this model basis model below.

$$\begin{cases} \frac{ds(t)}{dt} = -\delta i(t)s(t) \\ \frac{di(t)}{dt} = \delta i(t)s(t) \\ \varphi(t) = \psi + \pi\psi i(t) = \psi(1 + \tau\delta i(t)) \\ i(0) = i_0. \end{cases} \tag{2.3}$$

Using method of changing constant, we have $i(t) = \frac{1}{1+\left(\frac{1}{i_0}-1\right)e^{-\delta t}}$. So

$$\varphi(t) = \psi\left[1 + \tau\delta\frac{1}{1+\left(\frac{1}{i_0}-1\right)e^{-\delta t}}\right].$$

The second step is to build model for situation both of two spreading channels are all exist:

$$\begin{cases} \frac{ds(t)}{dt} = -\delta\varepsilon[1 + i(t)]i(t)s(t) \\ \frac{di(t)}{dt} = \delta\varepsilon[1 + i(t)]i(t)s(t) \\ \varphi(t) = \psi(1 + \tau\delta' i(t)) = \psi[1 + \tau\delta\varepsilon[1 + i(t)]i(t)] \\ i(0) = i_0. \end{cases} \tag{2.4}$$

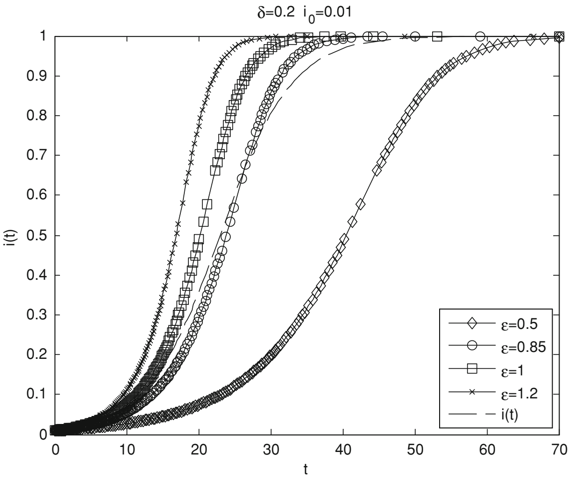


Fig. 2.4 Growth trend of $i(t)$ when $\delta = 0.2$, $i_0 = 0.01$ according to double channel model

Using method of changing constant too, we have:

$$i(t) = \left[\frac{1}{1 + \left(\frac{1}{i_0^2} - 1\right) e^{-2\delta\varepsilon t}} \right]^{1/2}, \tag{2.5}$$

$$\begin{aligned} \varphi(t) &= \psi(1 + \tau\delta' i(t)) \\ &= \psi \left[1 + \tau\delta\varepsilon \left[\left(\frac{1}{1 + \left(\frac{1}{i_0^2} - 1\right) e^{-2\delta\varepsilon t}} \right)^{1/2} + \frac{1}{1 + \left(\frac{1}{i_0^2} - 1\right) e^{-2\delta\varepsilon t}} \right] \right]. \end{aligned} \tag{2.6}$$

2.4 Model Analysis

We assumed there is group negative effect during the process of evolution which means apparent hesitation morale exists in prophase of the process and direct communication proportion will not be high. As to the double channel model, we make $i_0 = 0.01$, $\delta = 0.2$ which means the maximum value of ε is 2.5 and the thresholds of for negative effect are $\varepsilon_{+-} = 1/(1 + i_0) \approx 1$. With $i_0 = 0.01$, $\delta = 0.2$, Fig. 2.4 show us the growth trend of $i(t)$ when ε are respective 0.5, 0.85, 1, 1.2. In Fig. 2.4, the dashed line stands for the growth trend of $i(t)$ when $i_0 = 0.01$, $\delta = 0.2$ according to basis model.

Three important questions are reflected from Fig. 2.4. The moments the lines turn from convex trend to concave trend reflect the moment of exogenous factor's influence from strong to weak. The first question is the specific positions of the moments. We call these specific positions to be peak moment.

Because of the negative effect, some lines (for example $\varepsilon = 0.85$) will intersect with the line under basis model and then transcend it while some other lines (for example $\varepsilon = 0.5$) will never transcend the line under basis model. The second question is the range of ε during which the corresponding lines will conquer the negative effect and the third question is the conquer moments.

We call the range of ε during which lines can conquer the negative effect to be positive range and call the corresponding moments to be positive moment.

First of all, we will analyze the peak moment. Calculating quadratic differential of Eq. (2.5), we have

$$i''(t) = \frac{-2\delta^2\varepsilon^2\left(\frac{1}{i_0^2}-1\right)e^{-2\delta\varepsilon t}\left[1+\left(\frac{1}{i_0^2}-1\right)e^{-2\delta\varepsilon t}\right]+3\delta^2\varepsilon^2\left(\frac{1}{i_0^2}-1\right)^2 e^{-4\delta\varepsilon t}}{\left[1+\left(\frac{1}{i_0^2}-1\right)e^{-2\delta\varepsilon t}\right]^{5/2}}. \tag{2.7}$$

It is not certain for numerator's positive or negative cases in Eq. (2.7). So we have at peak moment

$$-2\delta^2\varepsilon^2\left(\frac{1}{i_0^2}-1\right)e^{-2\delta\varepsilon t_m}\left[1+\left(\frac{1}{i_0^2}-1\right)e^{-2\delta\varepsilon t_m}\right]+3\delta^2\varepsilon^2\left(\frac{1}{i_0^2}-1\right)^2 e^{-4\delta\varepsilon t_m}=0. \tag{2.8}$$

From Eq. (2.8) we have $t_m = -\frac{1}{2\delta\varepsilon}\ln\frac{2}{\frac{1}{i_0^2}-1}$.

Secondly, we will analyze positive range and positive moment. Based on Eq. (2.1), conquering negative effect means the change of δ' from less than δ to bigger than δ. That is: $\delta\varepsilon(1+i(t)) > \delta \Rightarrow \varepsilon > \frac{1}{1+i(t)}$. Because of

$$\lim_{t\to\infty}\left[\frac{1}{1+\left(\frac{1}{i_0^2}-1\right)e^{-2\delta\varepsilon t}}\right]^{1/2} = 1,$$

ε must meet $\varepsilon > \frac{1}{1+1} = 0.5$, so positive range is $\varepsilon \in \left(0.5, \frac{1}{1+i_0}\right)$.

For a given ε, positive moment must meet:

$$\delta\varepsilon(1+i(t_c)) = \delta \Rightarrow t_c = -\frac{1}{2\delta\varepsilon}\ln\frac{\frac{1}{\left(\frac{1}{\varepsilon}-1\right)^2}-1}{\frac{1}{i_0^2}-1}.$$

2.5 Influence of Power Structure's Feature to δ

In Fig. 2.2, features of power structure are decided by features of effective triangles while features of effective triangles are reflected in their weights of edges. The influence of weights to evolution is mainly reflected in influence to δ and π. Because δ and π change in the same direction, we will make our analysis focus on the influence of weights to δ.

More sensitive of knowledge source for exogenous factor or larger of the knowledge type changing space, bigger the possibility of knowledge source's changing action which means the bigger of δ. Different from diminishing return for resource input in physical manufacture, it is increasing return in knowledge manufacture. Knowledge sources will have more motion to revise their knowledge types when degrees of knowledge types are higher and then will be bigger. Overall, weights of edges and δ are changing in the same direction.

Hypothesis 4. affection way to δ from effective triangles is:

$$\delta = \lambda(w^1)^a(w^2)^b(w^3)^c,\ w^1 = \frac{1}{N}\sum_{x=1}^{N} w_x^1,\ w^2 = \frac{1}{N}\sum_{x=1}^{N} w_x^2,\ w^3 = \frac{1}{N}\sum_{x=1}^{N} w_x^3. \tag{2.9}$$

N is the total of effective triangles in knowledge network. $a \geq 0$, $b \geq 0$, $c \geq 0$ are elasticity parameters. One elasticity parameters is bigger, the corresponding weight's influence to δ will be weaker. $0 < \lambda < \frac{1}{(w^1)^a(w^2)^b(w^3)^c}$ is transformation parameter for influence effective triangles to δ. Effective triangles are established from the perspective of changing knowledge to response exogenous factor, but knowledge changing will influence knowledge source's business process deeply too. So we need consider influence to δ rom some other external factors such as business strategy, business status etc. These influences will enlarge or shrink the influence $(w^1)^a(w^2)^b(w^3)^c$ to δ.

Given λ and $a,\ b,\ c$, the influence from edges to δ will depend on how to get average weights. We assumed each edge's weight fit normal distribution. So the standard deviation and mean will be key roles in affecting average weights.

We set the total of knowledge source nodes to be 100, the total of knowledge types to be 30, the average types hold by every knowledge source node to be 7. Given $\lambda = 2,\ a = b = c = 1$, we assumed each weight fit normal distribution. We set mean of each weight to be 0.5 and the range of standard deviation to be $[0.1,\ 0.3]$. Figure 2.5 show us the relationship between standard deviation change and δ change.

From Fig. 2.6 we can see that δ increases smoothly and linear with mean's increasing and the speed of increasing is fast: δ changes in magnitude more than 0.3 while mean changes in magnitude about 0.2. So influence on δ from mean is obvious bigger than that from standard deviation.

Fig. 2.5 Relationship between standard deviation change and δ change

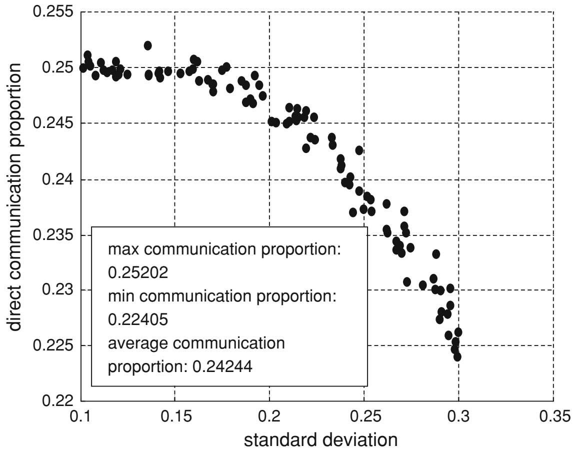
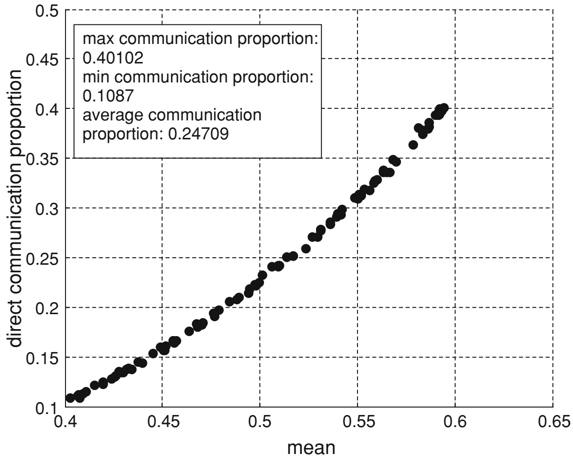


Fig. 2.6 Relationship between mean change and δ change



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