Knowledge Creation through Multimodal Communication

Marcus Berliant

京大リサーチアシスタント

and Masahisa Fujita

Washington University in St. Louis and Kyoto University

May 17, 2024

- Thank you for having me in to visit and attending this talk.
- Thank you Mori-sensei for your hospitality.
- Please feel free to interrupt with questions/comments/jokes at any time.
- This is the second presentation of this paper. It has changed drastically since the first presentation.
- Now about that first presentation...


30
山田洋次＝原作・監督
男はつらいよ
花も嵐も寅次郎

There are now $\pi + 2$ papers completed in this project:

- Dynamics of Knowledge Creation and Transfer: The Two Person Case (Elementary, in *International Journal of Economic Theory*)

Copies of the papers are available, e.g. from my web page.
There will be lots of pictures today.

There are now $\pi + 2$ papers completed in this project:

- Dynamics of Knowledge Creation and Transfer: The Two Person Case (Elementary, in *International Journal of Economic Theory*)
- Knowledge Creation as a Square Dance on the Hilbert Cube (Main, in the *International Economic Review*)

Copies of the papers are available, e.g. from my web page.
There will be lots of pictures today.

There are now $\pi + 2$ papers completed in this project:

- Dynamics of Knowledge Creation and Transfer: The Two Person Case (Elementary, in *International Journal of Economic Theory*)
- Knowledge Creation as a Square Dance on the Hilbert Cube (Main, in the *International Economic Review*)
- The Dynamics of Knowledge Diversity and Economic Growth (Application, in the *Southern Economic Journal*)

Copies of the papers are available, e.g. from my web page.
There will be lots of pictures today.

There are now $\pi + 2$ papers completed in this project:

- Dynamics of Knowledge Creation and Transfer: The Two Person Case (Elementary, in *International Journal of Economic Theory*)
- Knowledge Creation as a Square Dance on the Hilbert Cube (Main, in the *International Economic Review*)
- The Dynamics of Knowledge Diversity and Economic Growth (Application, in the *Southern Economic Journal*)
- Culture and Diversity in Knowledge Creation (Application with cites to religious texts, *Regional Science and Urban Economics*)

Copies of the papers are available, e.g. from my web page.
There will be lots of pictures today.

There are now $\pi + 2$ papers completed in this project:

- Dynamics of Knowledge Creation and Transfer: The Two Person Case (Elementary, in *International Journal of Economic Theory*)
- Knowledge Creation as a Square Dance on the Hilbert Cube (Main, in the *International Economic Review*)
- The Dynamics of Knowledge Diversity and Economic Growth (Application, in the *Southern Economic Journal*)
- Culture and Diversity in Knowledge Creation (Application with cites to religious texts, *Regional Science and Urban Economics*)
- This paper

Copies of the papers are available, e.g. from my web page.
There will be lots of pictures today.

There are now $\pi + 2$ papers completed in this project:

- Dynamics of Knowledge Creation and Transfer: The Two Person Case (Elementary, in *International Journal of Economic Theory*)
- Knowledge Creation as a Square Dance on the Hilbert Cube (Main, in the *International Economic Review*)
- The Dynamics of Knowledge Diversity and Economic Growth (Application, in the *Southern Economic Journal*)
- Culture and Diversity in Knowledge Creation (Application with cites to religious texts, *Regional Science and Urban Economics*)
- This paper
- AI paper? Now over 200 pages.

Copies of the papers are available, e.g. from my web page.
There will be lots of pictures today.

Expositional Note

- The papers are long and have quite a bit of algebra in them. That is because we prove *everything* analytically. This paper is 86 pages short.

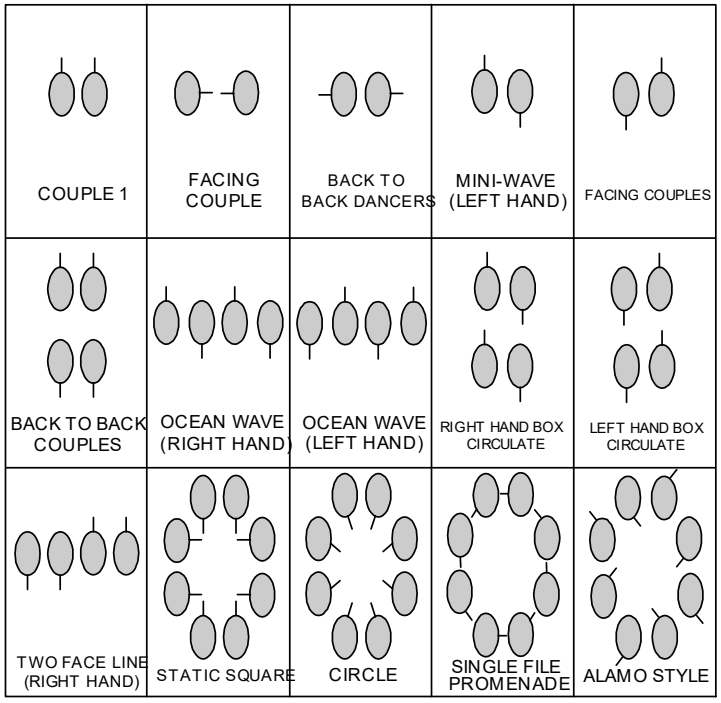
Expositional Note

- The papers are long and have quite a bit of algebra in them. That is because we prove *everything* analytically. This paper is 86 pages short.
- In contrast, it is easy to present this work quickly using only pictures, including both the statement of results and idea of proofs. You just have to get the hang of it.

Expositional Note

- The papers are long and have quite a bit of algebra in them. That is because we prove *everything* analytically. This paper is 86 pages short.
- In contrast, it is easy to present this work quickly using only pictures, including both the statement of results and idea of proofs. You just have to get the hang of it.
- There will be a minimum of notation and lots of pictures and hand waving.

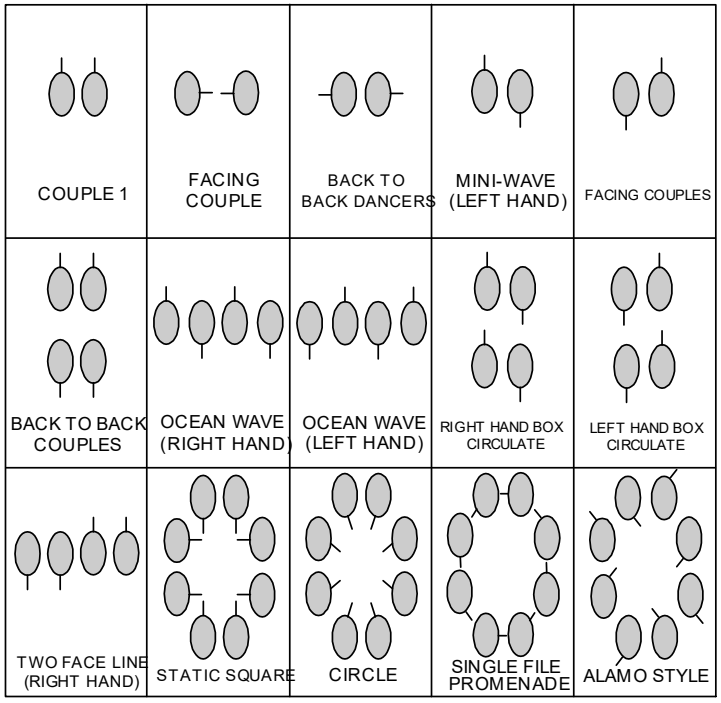
Abstract from First Paper:



Source: http://www.penrod-sq-dancing.com/fasr1.html

- What do you know about square dancing? It's a metaphor...

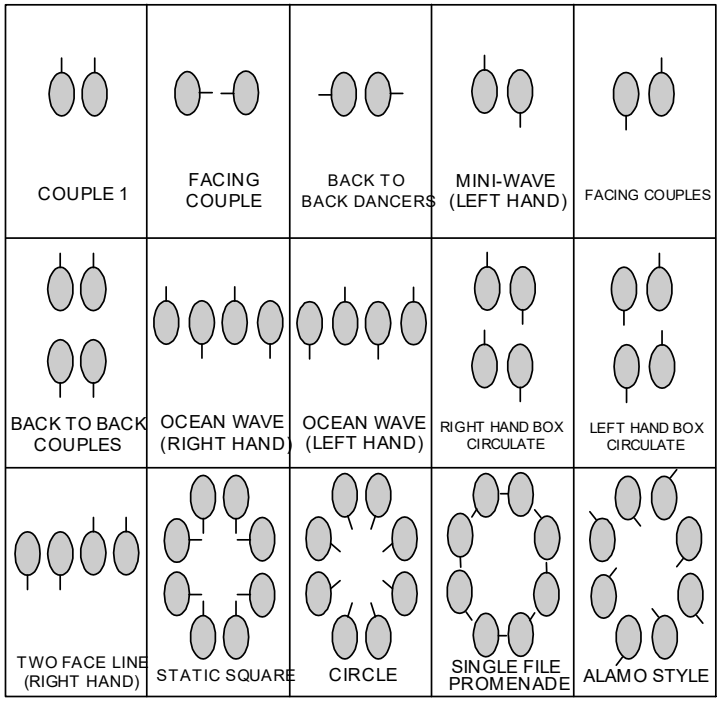
Abstract from First Paper:



Source: http://www.penrod-sq-dancing.com/fasr1.html

- What do you know about square dancing? It's a metaphor...
- This was the abstract, until Masa decided that we had to get serious. (Me, serious?)

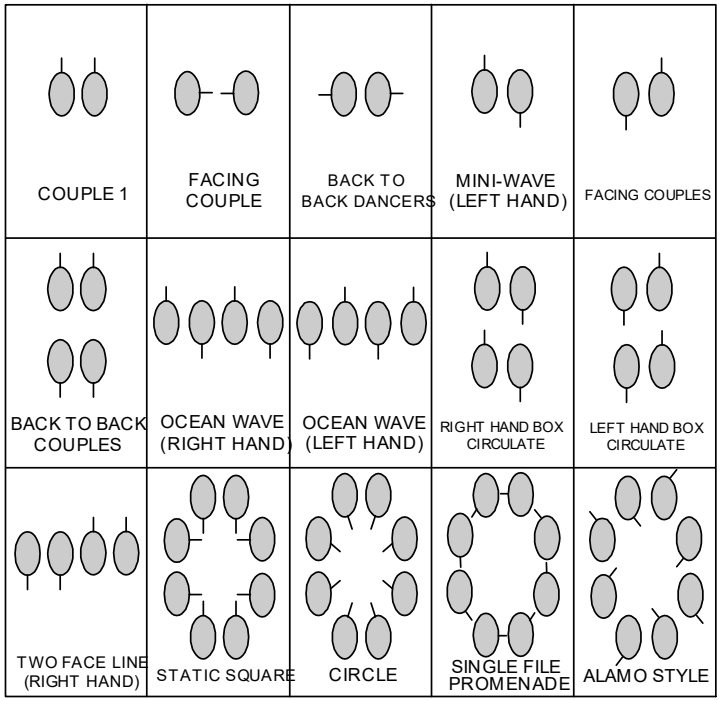
Abstract from First Paper:



Source: http://www.penrod-sq-dancing.com/fasr1.html

- What do you know about square dancing? It's a metaphor...
- This was the abstract, until Masa decided that we had to get serious. (Me, serious?)
- I'm not Masa, so you will have to settle for second best.

Abstract from First Paper:



Source: http://www.penrod-sq-dancing.com/fasr1.html

- What do you know about square dancing? It's a metaphor...
- This was the abstract, until Masa decided that we had to get serious. (Me, serious?)
- I'm not Masa, so you will have to settle for second best.
- The first line describes the process of writing these papers.

Outline of this Talk

I. Motivation and related literature
II. The model basics for all of the papers
Short Rest
III. The Model with 2 persons in the stationary state
IV. Effect of F2F lead time on the mode of communication and joint knowledge productivity
V. Knowledge composition, productivity, and choice of work mode
VI. Dynamics of the two-person system
VII. Summary, correcting inefficiencies, extensions
Don't worry, each section is short!

Motivation: Questions About Knowledge Creation

- How should the process of knowledge creation be modeled?

Motivation: Questions About Knowledge Creation

- How should the process of knowledge creation be modeled?
- How does the knowledge creation process function when there are multiple ways for people to communicate, for example face to face or using the internet?

Motivation: Questions About Knowledge Creation

- How should the process of knowledge creation be modeled?
- How does the knowledge creation process function when there are multiple ways for people to communicate, for example face to face or using the internet?
- Relative to the one communication channel case, what different patterns of joint research among knowledge workers emerge, and how is the productivity of research work affected?

Motivation: Questions About Knowledge Creation

- How should the process of knowledge creation be modeled?
- How does the knowledge creation process function when there are multiple ways for people to communicate, for example face to face or using the internet?
- Relative to the one communication channel case, what different patterns of joint research among knowledge workers emerge, and how is the productivity of research work affected?
- Under what conditions are the conceptual and technical phases of knowledge production best accomplished through each of the communication channels?

Motivation: Tacit Knowledge

- When analyzing the dynamics of knowledge creation, as we do here, the concept of *tacit knowledge* among the people creating new knowledge arises organically.

Motivation: Tacit Knowledge

- When analyzing the dynamics of knowledge creation, as we do here, the concept of *tacit knowledge* among the people creating new knowledge arises organically.
- As tacit knowledge is the part of knowledge that is not manifested in the final product, readers will recognize it as what is learned by authors in the academic research setting that is not explicitly embedded in a published paper, including this one.

Motivation: Tacit Knowledge

- When analyzing the dynamics of knowledge creation, as we do here, the concept of *tacit knowledge* among the people creating new knowledge arises organically.
- As tacit knowledge is the part of knowledge that is not manifested in the final product, readers will recognize it as what is learned by authors in the academic research setting that is not explicitly embedded in a published paper, including this one.
- What are the efficiency consequences of tacit knowledge?

Motivation: Tacit Knowledge

- When analyzing the dynamics of knowledge creation, as we do here, the concept of *tacit knowledge* among the people creating new knowledge arises organically.
- As tacit knowledge is the part of knowledge that is not manifested in the final product, readers will recognize it as what is learned by authors in the academic research setting that is not explicitly embedded in a published paper, including this one.
- What are the efficiency consequences of tacit knowledge?
- What kind of innovation policy is appropriate in the presence of tacit knowledge?

Motivation: Tacit Knowledge

- When analyzing the dynamics of knowledge creation, as we do here, the concept of *tacit knowledge* among the people creating new knowledge arises organically.
- As tacit knowledge is the part of knowledge that is not manifested in the final product, readers will recognize it as what is learned by authors in the academic research setting that is not explicitly embedded in a published paper, including this one.
- What are the efficiency consequences of tacit knowledge?
- What kind of innovation policy is appropriate in the presence of tacit knowledge?
- *Can artificial intelligence have tacit knowledge?*

Motivation: Tacit Knowledge

- When analyzing the dynamics of knowledge creation, as we do here, the concept of *tacit knowledge* among the people creating new knowledge arises organically.
- As tacit knowledge is the part of knowledge that is not manifested in the final product, readers will recognize it as what is learned by authors in the academic research setting that is not explicitly embedded in a published paper, including this one.
- What are the efficiency consequences of tacit knowledge?
- What kind of innovation policy is appropriate in the presence of tacit knowledge?
- *Can artificial intelligence have tacit knowledge?*
- To address these questions, we must first build a model that incorporates tacit knowledge.

Motivation: Tacit Knowledge

- When analyzing the dynamics of knowledge creation, as we do here, the concept of *tacit knowledge* among the people creating new knowledge arises organically.
- As tacit knowledge is the part of knowledge that is not manifested in the final product, readers will recognize it as what is learned by authors in the academic research setting that is not explicitly embedded in a published paper, including this one.
- What are the efficiency consequences of tacit knowledge?
- What kind of innovation policy is appropriate in the presence of tacit knowledge?
- *Can artificial intelligence have tacit knowledge?*
- To address these questions, we must first build a model that incorporates tacit knowledge.
- We are not aware of any formal models of either multimodal communication or tacit knowledge in the prior literature.

Essential Features:

- History matters, agents change

Essential Features:

- History matters, agents change
- Too much in common $\longrightarrow$ not enough originality, low productivity

Essential Features:

- History matters, agents change
- Too much in common $\longrightarrow$ not enough originality, low productivity
- Too little in common $\longrightarrow$ communication difficult, low productivity

Essential Features:

- History matters, agents change
- Too much in common $\longrightarrow$ not enough originality, low productivity
- Too little in common $\longrightarrow$ communication difficult, low productivity
- Endogenous Agent Heterogeneity - Horizontal

On the one hand:
Whether working alone or with others, a person's accumulated knowledge base might not be compatible with that of another person with whom they've had no contact.

On the other hand:
If two people have been working together for a long time, their base of knowledge in common increases, and their partnership eventually becomes less productive.

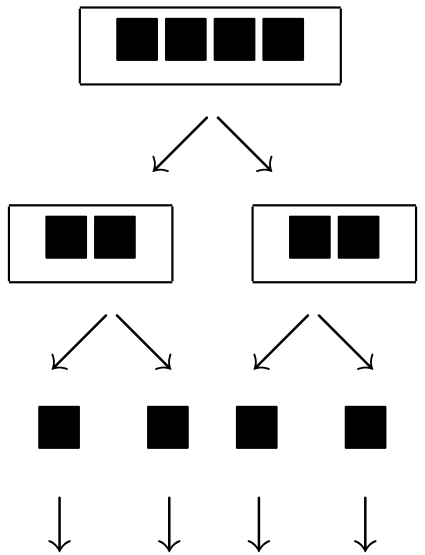
We investigate the *permanent* effects of knowledge creation and growth.

Useful Analogy

Working jointly to share ideas and create new ones

Partner dancing

(For now, 3 or 4 cannot dance together, though couples can dance simultaneously.)
People can work or dance alone.



(Macro Models)

(Our Work)

True Microfoundations

(We Are Trying to Get Here)

A Robot Economist?

Preview of the Results

- Deterministic Framework

Preview of the Results

- Deterministic Framework
- Myopic Agents

Preview of the Results

- Deterministic Framework
- Myopic Agents
- In contrast with our previous work, here we separate the knowledge creation process into conceptual and technical phases, and allow researchers to choose the mode of communication, F2F or the net, that suits them best in each phase.

Preview: Modes of Communication

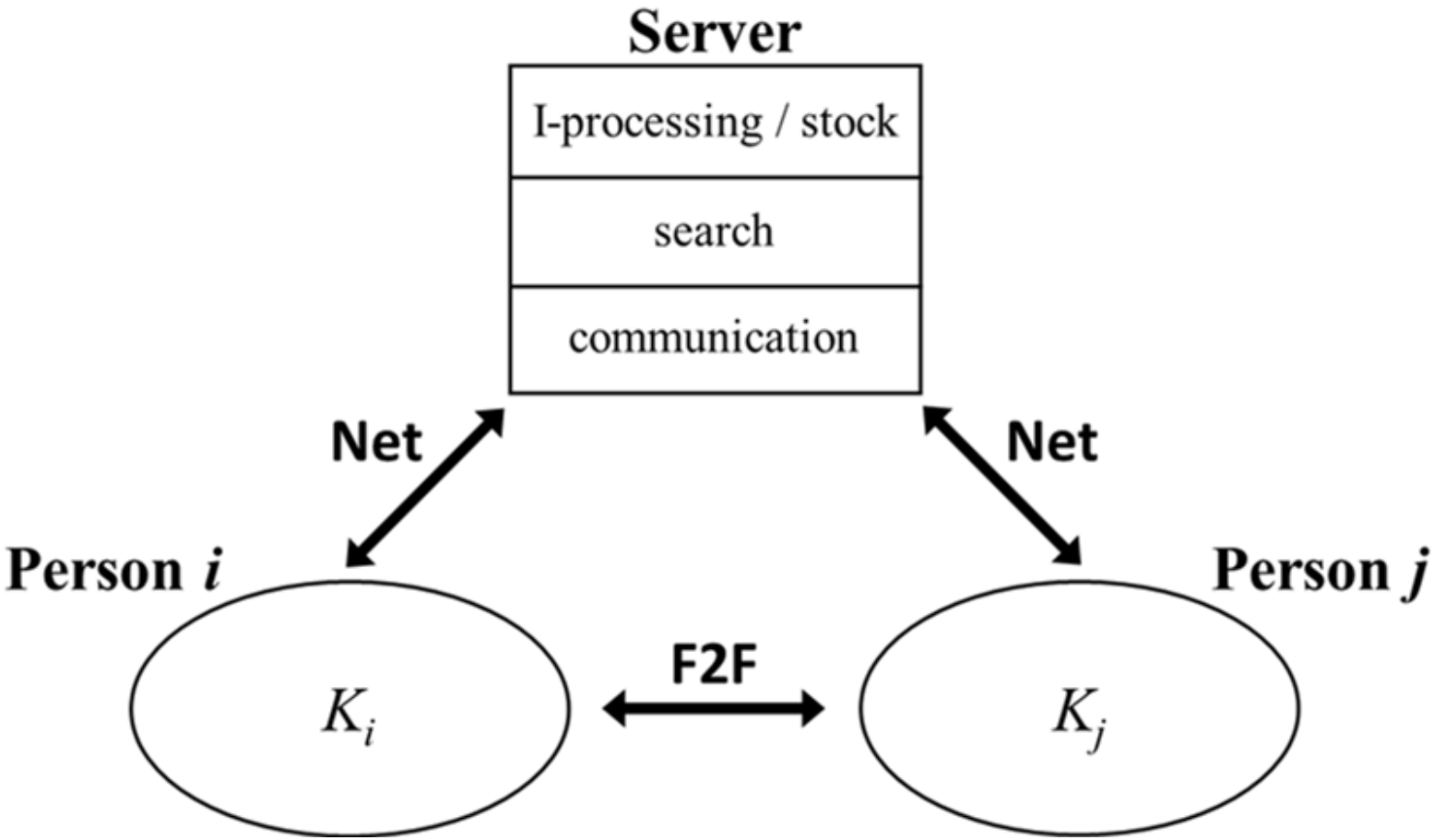


Figure 1. Knowledge creation through multiple modes of communication

Preview: Main Results

1. First, we find that a crucial parameter in the model is the *lead time* for F2F communication. What we mean by lead time is the fixed cost for communicating F2F, such as the cost of commuting to the office.

Preview: Main Results

1. First, we find that a crucial parameter in the model is the *lead time* for F2F communication. What we mean by lead time is the fixed cost for communicating F2F, such as the cost of commuting to the office.
2. Second, in contrast with our previous work, the steady state will not, in general, be the state with highest productivity. The net effect is that achieving and maintaining the highest productivity profile of knowledge in common and differential knowledge requires more heterogeneity or larger research groups than we found in our previous work.

Preview: Main Results

1. First, we find that a crucial parameter in the model is the *lead time* for F2F communication. What we mean by lead time is the fixed cost for communicating F2F, such as the cost of commuting to the office.
2. Second, in contrast with our previous work, the steady state will not, in general, be the state with highest productivity. The net effect is that achieving and maintaining the highest productivity profile of knowledge in common and differential knowledge requires more heterogeneity or larger research groups than we found in our previous work.
3. Third, the effect of tacit knowledge on knowledge productivity is not internalized by the knowledge workers.

Preview: Main Results

1. First, we find that a crucial parameter in the model is the *lead time* for F2F communication. What we mean by lead time is the fixed cost for communicating F2F, such as the cost of commuting to the office.
2. Second, in contrast with our previous work, the steady state will not, in general, be the state with highest productivity. The net effect is that achieving and maintaining the highest productivity profile of knowledge in common and differential knowledge requires more heterogeneity or larger research groups than we found in our previous work.
3. Third, the effect of tacit knowledge on knowledge productivity is not internalized by the knowledge workers.
4. Fourth, as net and transport technology improves, knowledge composition becomes more important than geographical distance in the choice of research partners.

Preview: Application to Covid Restrictions (Appendix A)

- Applying this framework to pandemic restrictions, we show, for example, how the productivity of knowledge workers with longer commutes to work is affected less than those with shorter commutes when pandemic restrictions on face to face work are implemented.

Preview: Application to Covid Restrictions (Appendix A)

- Applying this framework to pandemic restrictions, we show, for example, how the productivity of knowledge workers with longer commutes to work is affected less than those with shorter commutes when pandemic restrictions on face to face work are implemented.
- This application requires the introduction of multimodal communication to our model.

Related Literature

- Covid, etc.

Related Literature

- Covid, etc.
- See paper for literature review

Related Literature

- Covid, etc.
- See paper for literature review
- Part of our framework here is based on the insightful empirical paper by Lin et al (2022).

Related Literature

- Covid, etc.
- See paper for literature review
- Part of our framework here is based on the insightful empirical paper by Lin et al (2022).
- They break down the knowledge creation process into *conceptual* and *technical* phases.

Related Literature

- Covid, etc.
- See paper for literature review
- Part of our framework here is based on the insightful empirical paper by Lin et al (2022).
- They break down the knowledge creation process into *conceptual* and *technical* phases.
- The early conceptual phase involves tacit knowledge deployment, whereas the later technical phase involves explicit knowledge.

Related Literature

- Covid, etc.
- See paper for literature review
- Part of our framework here is based on the insightful empirical paper by Lin et al (2022).
- They break down the knowledge creation process into *conceptual* and *technical* phases.
- The early conceptual phase involves tacit knowledge deployment, whereas the later technical phase involves explicit knowledge.
- Using a large data set, *they find that face to face communication is more effective in the conceptual phase,* whereas remote teams can be effective in the technical phase.

The Basic Model - Previous Papers: What is an Idea?

This Paper | Recipe for Udon Noodles | ... ∞

- Everyone can read the labels, but it takes time to learn the contents (it takes no time to read the labels).

The Basic Model - Previous Papers: What is an Idea?

This Paper | Recipe for Udon Noodles | ... ∞

- Everyone can read the labels, but it takes time to learn the contents (it takes no time to read the labels).
- Ideas are ordered (k)

The Basic Model - Previous Papers: What is an Idea?

This Paper | Recipe for Udon Noodles | ... ∞

- Everyone can read the labels, but it takes time to learn the contents (it takes no time to read the labels).
- Ideas are ordered (k)
- Time is continuous ($\mathbb{R}_+$)

The Basic Model - Previous Papers: What is an Idea?

This Paper | Recipe for Udon Noodles | ... ∞

- Everyone can read the labels, but it takes time to learn the contents (it takes no time to read the labels).
- Ideas are ordered (k)
- Time is continuous ($\mathbb{R}_+$)
- $x_i^k(t) = \begin{cases} 1 \text{ if person } i \text{ knows idea } k \text{ at time } t \\ 0 \text{ otherwise} \end{cases}$

The Basic Model - Previous Papers: What is an Idea?

This Paper | Recipe for Udon Noodles | ... ∞

- Everyone can read the labels, but it takes time to learn the contents (it takes no time to read the labels).
- Ideas are ordered (k)
- Time is continuous ($\mathbb{R}_+$)
- $x_i^k(t) = \begin{cases} 1 \text{ if person } i \text{ knows idea } k \text{ at time } t \\ 0 \text{ otherwise} \end{cases}$
- Knowledge of person i at time t :
  $K_i(t) = (x_i^1(t), x_i^2(t), ...) \in \{0,1\}^\infty$ (Specifies set of ideas known by person i at time t.)

Knowledge Creation

- Creation of new ideas alone - dancing alone: Opening a box not opened previously by anyone.

Knowledge Creation

- Creation of new ideas alone - dancing alone: Opening a box not opened previously by anyone.
- Joint creation of new ideas: Opening a box not opened previously by anyone *together*. Becomes knowledge in common.

Knowledge Creation

- Creation of new ideas alone - dancing alone: Opening a box not opened previously by anyone.
- Joint creation of new ideas: Opening a box not opened previously by anyone *together*. Becomes knowledge in common.
- All take time. Opportunity cost is time in this model.

The *Hilbert Cube* $= [0,1]^H$ where $H = \{1,2,3,...\}$
So for all i, for all t, $K_i(t)$ is a vertex of the Hilbert cube.

For our analysis today, we treat ideas symmetrically, so we don't need to know $K_i(t)$, but only some statistics about $K_i(t)$:

- # of ideas known by i at t:

$$n_i(t) = \sum_{k=1}^{\infty} x_i^k(t)$$

The *Hilbert Cube* $= [0,1]^H$ where $H = \{1,2,3,...\}$
So for all i, for all t, $K_i(t)$ is a vertex of the Hilbert cube.

For our analysis today, we treat ideas symmetrically, so we don't need to know $K_i(t)$, but only some statistics about $K_i(t)$:

- # of ideas known by i at t:

$$n_i(t) = \sum_{k=1}^{\infty} x_i^k(t)$$

- # of ideas known by both i and j at t:

$$n_{ij}^c(t) = \sum_{k=1}^{\infty} x_i^k(t) \cdot x_j^k(t)$$

The *Hilbert Cube* $= [0,1]^H$ where $H = \{1,2,3,...\}$
So for all i, for all t, $K_i(t)$ is a vertex of the Hilbert cube.

For our analysis today, we treat ideas symmetrically, so we don't need to know $K_i(t)$, but only some statistics about $K_i(t)$:

- # of ideas known by i at t:

$$n_i(t) = \sum_{k=1}^{\infty} x_i^k(t)$$

- # of ideas known by both i and j at t:

$$n_{ij}^c(t) = \sum_{k=1}^{\infty} x_i^k(t) \cdot x_j^k(t)$$

- # of ideas known by i but not by j at t:

$$n_{ij}^d(t) = n_i(t) - n_{ij}^c(t)$$

The 2 Person Model: Choices

Consider 2 agents.

- If either does not want to meet, then no meeting occurs.

The 2 Person Model: Choices

Consider 2 agents.

- If either does not want to meet, then no meeting occurs.
- If both want to meet, then there is a meeting. Myopic core.

- Framework above is useful for explaining the model. What follows are the real assumptions. All rates are per unit of time:

- Framework above is useful for explaining the model. What follows are the real assumptions. All rates are per unit of time:
- Individual Production:

$$y_i(t) = n_i(t) = \text{felicity}$$

- Framework above is useful for explaining the model. What follows are the real assumptions. All rates are per unit of time:
- Individual Production:

$$y_i(t) = n_i(t) = \text{felicity}$$

- New ideas created alone at t:

$$\alpha \cdot n_i(t)$$

- Framework above is useful for explaining the model. What follows are the real assumptions. All rates are per unit of time:
- Individual Production:

$$y_i(t) = n_i(t) = \text{felicity}$$

- ■ New ideas created alone at t:

$$\alpha \cdot n_i(t)$$

- ■ New ideas created jointly with a meeting at t:

$$\beta \left[n_{ij}^{c}(t) \cdot n_{ij}^{d}(t) \cdot n_{ji}^{d}(t) \right]^{\frac{1}{3}}$$

- Framework above is useful for explaining the model. What follows are the real assumptions. All rates are per unit of time:
- Individual Production:

$$y_i(t) = n_i(t) = \text{felicity}$$

- ■ New ideas created alone at t:

$$\alpha \cdot n_i(t)$$

- ■ New ideas created jointly with a meeting at t:

$$\beta \left[n_{ij}^c(t) \cdot n_{ij}^d(t) \cdot n_{ji}^d(t) \right]^{\frac{1}{3}}$$

- Best = Even Split - % common ideas, % ideas exclusive to i, % ideas exclusive to j. Overlap for communication, but agents are different. Originality. Like Masa and Marcus, they know different stuff. Functional form more general in many of the papers.

- Agents are myopic. Their only choice is meeting or not. Choose option with higher increase in rate of output:

$$\max \frac{dy/dt}{y}$$

If tied:

$$\max \frac{d}{dt}\left(\frac{dy/dt}{y}\right)$$

- Agents are myopic. Their only choice is meeting or not. Choose option with higher increase in rate of output:

$$\max \frac{dy/dt}{y}$$

If tied:

$$\max \frac{d}{dt}\left(\frac{dy/dt}{y}\right)$$

- The perfect foresight version of the model is difficult, but we have some results with it.

- Divide all endogenous variables ("n") by the total # of ideas (for both) to obtain normalized variables "m", interpreted as percentages.

$$m^c + m^d_{ij} + m^d_{ji} = 1$$

- Divide all endogenous variables ("n") by the total # of ideas (for both) to obtain normalized variables "m", interpreted as percentages.

$$m^c + m^d_{ij} + m^d_{ji} = 1$$

- Know m^d_{ij}, $m^d_{ji} \Longrightarrow$ know m^c

- Divide all endogenous variables ("n") by the total # of ideas (for both) to obtain normalized variables "m", interpreted as percentages.

$$m^c + m^d_{ij} + m^d_{ji} = 1$$

- Know m^d_{ij}, $m^d_{ji} \Longrightarrow$ know m^c
- We are now within δ of having all the notation. Most everything else will be pictures.

- Divide all endogenous variables ("n") by the total # of ideas (for both) to obtain normalized variables "m", interpreted as percentages.

$$m^c + m^d_{ij} + m^d_{ji} = 1$$

- Know m^d_{ij}, $m^d_{ji} \Longrightarrow$ know m^c
- We are now within δ of having all the notation. Most everything else will be pictures.
- $\delta = 0 \Longleftrightarrow$ No meeting

- Divide all endogenous variables ("n") by the total # of ideas (for both) to obtain normalized variables "m", interpreted as percentages.

$$m^c + m^d_{ij} + m^d_{ji} = 1$$

- Know m^d_{ij}, $m^d_{ji} \Longrightarrow$ know m^c
- We are now within δ of having all the notation. Most everything else will be pictures.
- $\delta = 0 \Longleftrightarrow$ No meeting
- $\delta = 1 \Longleftrightarrow$ Meeting

A Short Rest - The Arch

Cardinals

The Model with 2 Persons in the Stationary State

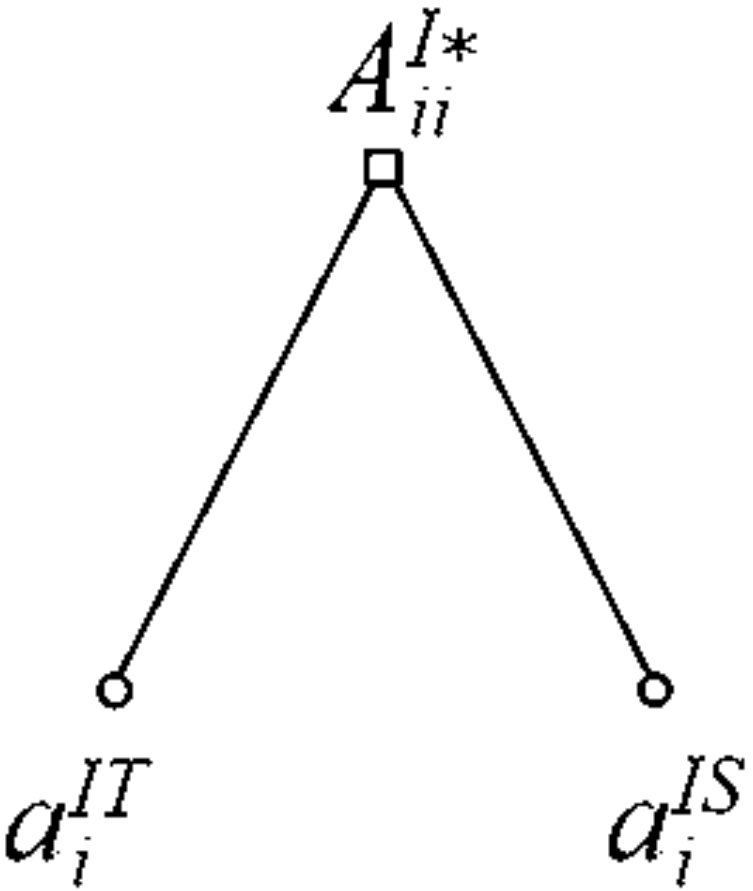


Figure 2. The activity tree for knowledge creation by person i in Isolation.

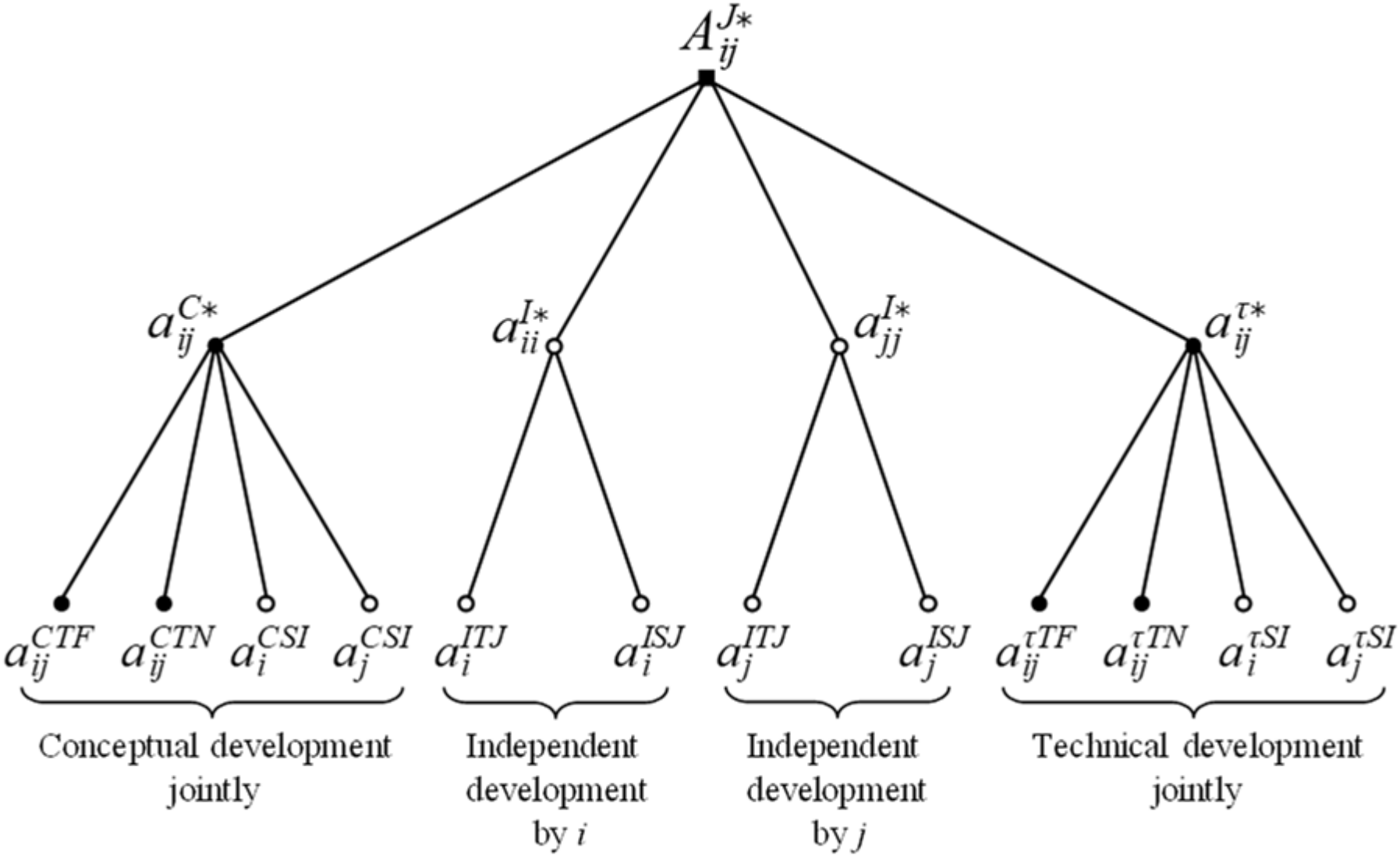


Figure 3. The activity tree for joint knowledge creation

The Structure of One Period - JOINT Work

Lead Time

- λ_{CF} = Time spent in Conceptual work Face to face

Lead Time

- λ_{CF} = Time spent in Conceptual work Face to face
- λ_{CN} = Time spent in Conceptual work on the Net

Lead Time

- λ_{CF} = Time spent in Conceptual work Face to face
- λ_{CN} = Time spent in Conceptual work on the Net
- The two persons can jointly choose λ_{CF} and λ_{CN} freely, subject to the following constraint:

$$(1+\varepsilon_F)\cdot\lambda_{CF}+\lambda_{CN}=1,\quad \lambda_{CF}\geq 0,\ \lambda_{CN}\geq 0$$

where $\varepsilon_F > 0$ represents the *lead time* of joint thinking for conceptual development F2F.

Lead Time

- λ_{CF} = Time spent in Conceptual work Face to face
- λ_{CN} = Time spent in Conceptual work on the Net
- The two persons can jointly choose λ_{CF} and λ_{CN} freely, subject to the following constraint:

$$(1+\varepsilon_F)\cdot\lambda_{CF}+\lambda_{CN}=1,\quad \lambda_{CF}\geq 0,\ \lambda_{CN}\geq 0$$

  where $\varepsilon_F > 0$ represents the *lead time* of joint thinking for conceptual development F2F.

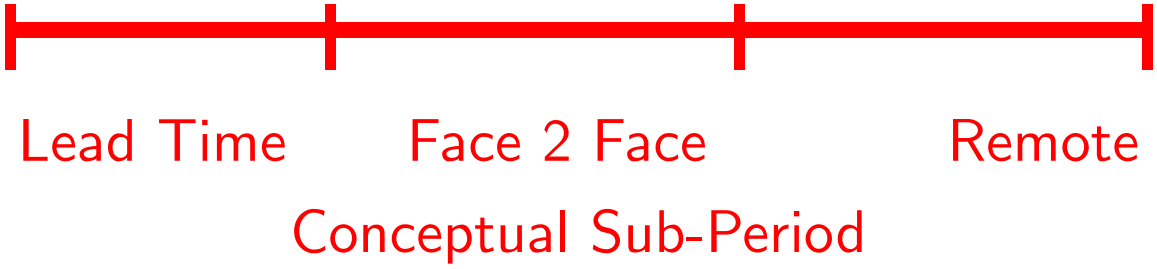
- In practice, ε_F reflects the time cost of preparing for a F2F meeting, such as commuting time to the common CBD office (or common university), or travel time between two cities or two countries where each of the two persons reside separately.

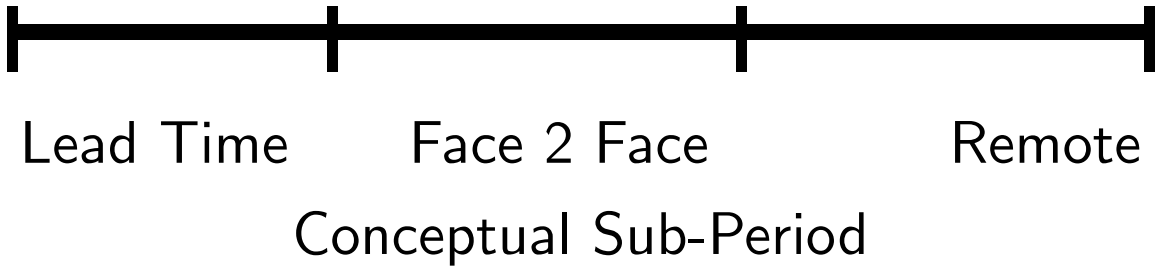
Lead Time

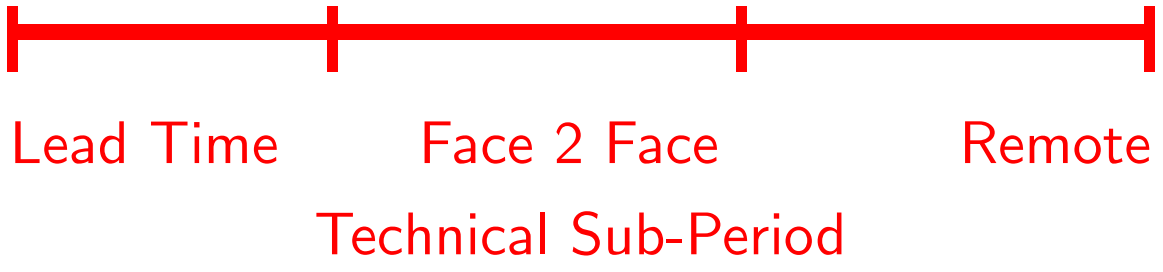
- λ_{CF} = Time spent in Conceptual work Face to face
- λ_{CN} = Time spent in Conceptual work on the Net
- The two persons can jointly choose λ_{CF} and λ_{CN} freely, subject to the following constraint:

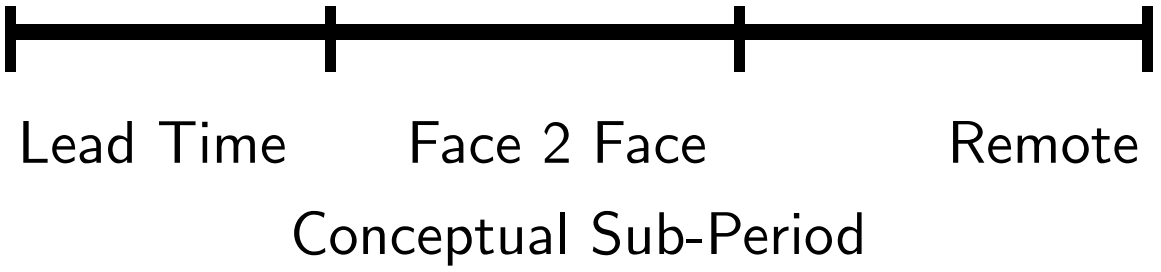
$$(1+\varepsilon_F)\cdot\lambda_{CF}+\lambda_{CN}=1,\quad \lambda_{CF}\geq 0,\ \lambda_{CN}\geq 0$$

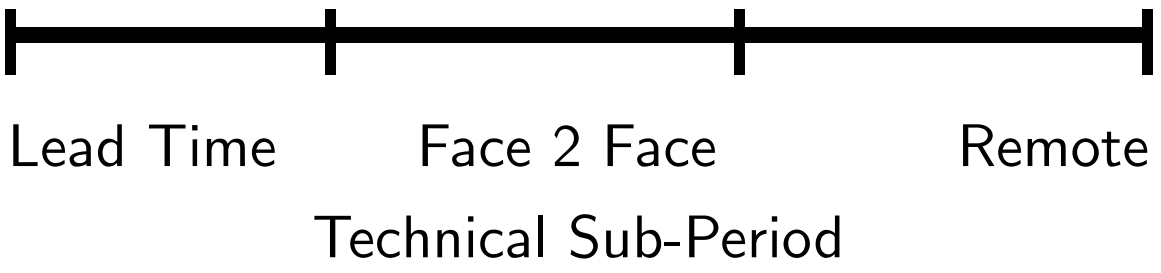
  where $\varepsilon_F > 0$ represents the *lead time* of joint thinking for conceptual development F2F.
- In practice, ε_F reflects the time cost of preparing for a F2F meeting, such as commuting time to the common CBD office (or common university), or travel time between two cities or two countries where each of the two persons reside separately.
- Lead time for Net is normalized to zero.


Lead Time
Face 2 Face
Remote
Conceptual Sub-Period

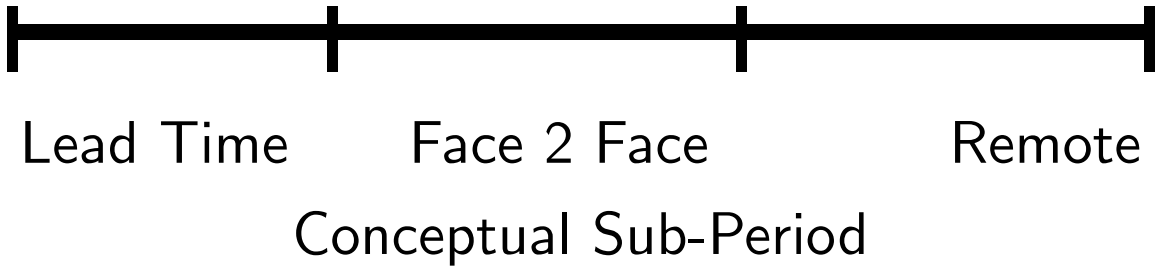

Lead Time
Face 2 Face
Remote
Conceptual Sub-Period

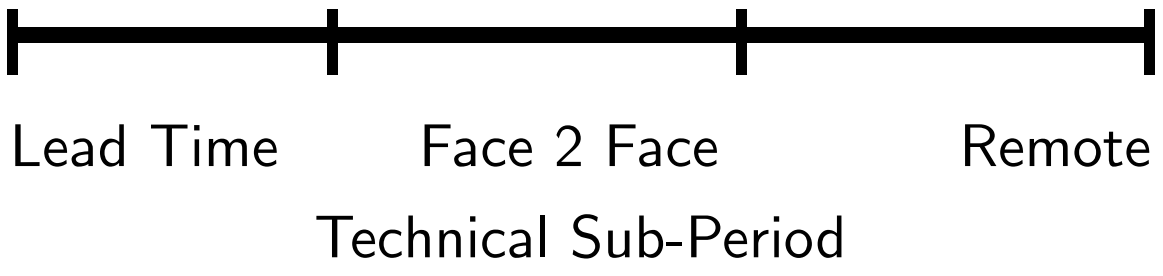

Lead Time
Face 2 Face
Remote
Technical Sub-Period





- Workers can choose % mode of communication in *each* Sub-Period: F2F (at work) and Remote (at home)





- Workers can choose % mode of communication in *each* Sub-Period: F2F (at work) and Remote (at home)
- Covid restrictions limit the sum total of F2F across Conceptual and Technical sub-periods.

Effect of F2F lead time on the mode of communication and joint knowledge productivity

- *Assumption 1.* In both the phase of conceptual development and the phase of technical development, thinking jointly F2F is more effective than thinking jointly through the Net. Furthermore, the effectiveness of F2F relative to the Net is greater in conceptual development than in technical development.

Effect of F2F lead time on the mode of communication and joint knowledge productivity

- *Assumption 1*. In both the phase of conceptual development and the phase of technical development, thinking jointly F2F is more effective than thinking jointly through the Net. Furthermore, the effectiveness of F2F relative to the Net is greater in conceptual development than in technical development.
- This assumption is based on two ideas. First, tacit knowledge is best developed and exploited face to face. Nonaka and Takeuchi (1995) provide case studies, including the invention of the first automatic home bakery machine by Matsushita and the development of the City car model by Honda. Both involved the exploitation of tacit knowledge. Second, empirical evidence developed by Lin et al (2022) is consistent with this assumption.

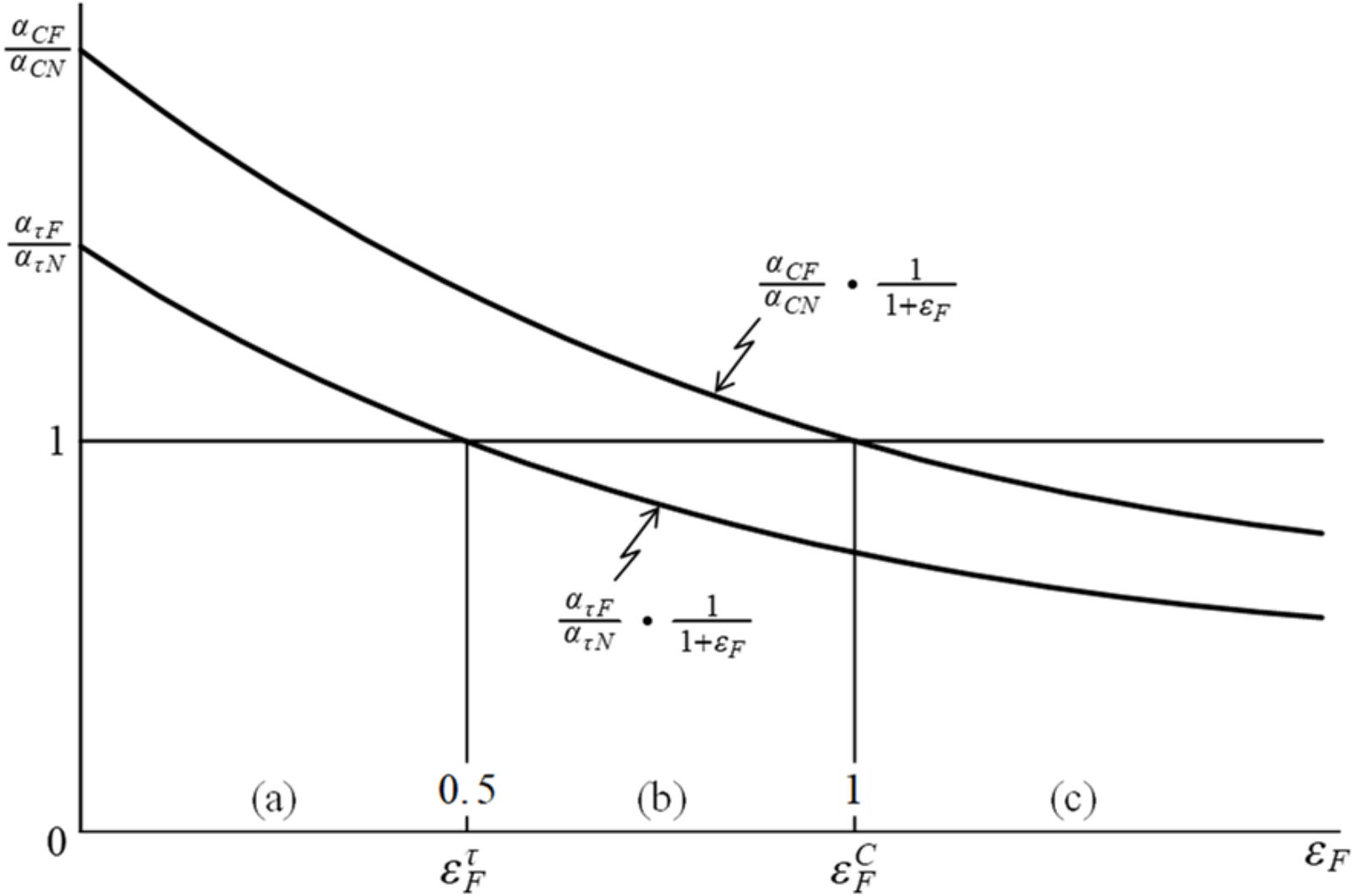


Figure 4. The parameter value of F2F lead-time and the three ranges of communication mode ε_F when $\alpha_{CF}/\alpha_{CN} = 2$ and $\alpha_{\tau F}/\alpha_{\tau N} = 1.5$.

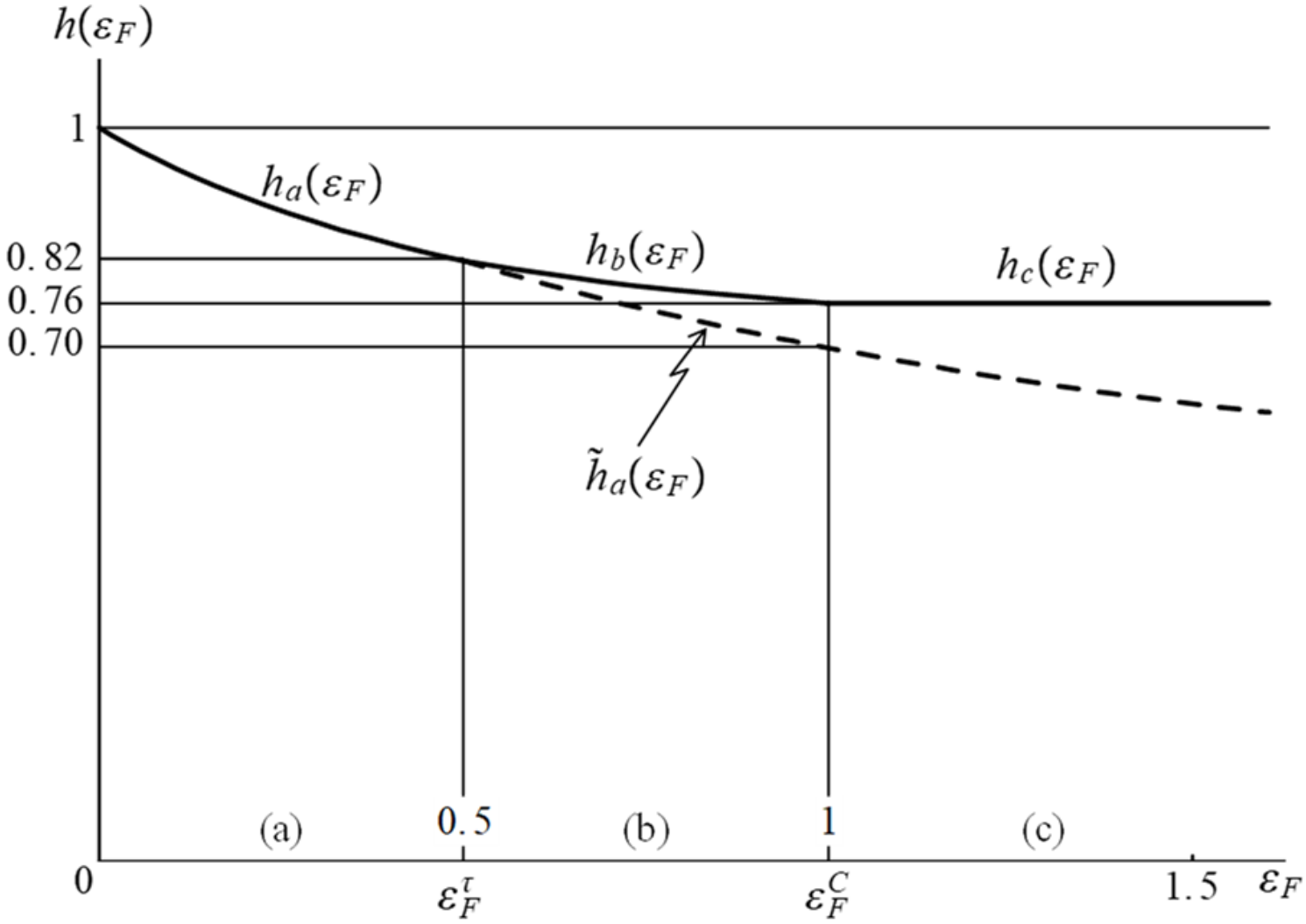


Figure 5. $h(\varepsilon_F)$ is the *relative productivity of joint work at* ε_F in comparison with the productivity of joint work at $\varepsilon_F = 0$ over the three ranges of parameter ε_F.

No Net Technology

- Figure 5 can be interpreted as representing the impact of the development of net-communication technology, where the broken curve represents the relative productivity at each ε_F when *no net-technology is available*, whereas the real curve represents the relative productivity under the effective use of *modern net-technology*.

No Net Technology

- Figure 5 can be interpreted as representing the impact of the development of net-communication technology, where the broken curve represents the relative productivity at each ε_F when *no net-technology is available*, whereas the real curve represents the relative productivity under the effective use of *modern net-technology*.
- The case where no net-technology is available is studied by Inoue et al (2022), since the internet didn't exist during the Spanish flu epidemic.

No Net Technology

- Figure 5 can be interpreted as representing the impact of the development of net-communication technology, where the broken curve represents the relative productivity at each ε_F when *no net-technology is available*, whereas the real curve represents the relative productivity under the effective use of *modern net-technology*.
- The case where no net-technology is available is studied by Inoue et al (2022), since the internet didn't exist during the Spanish flu epidemic.
- Without this substitute for F2F, the effect on knowledge creation was severe.

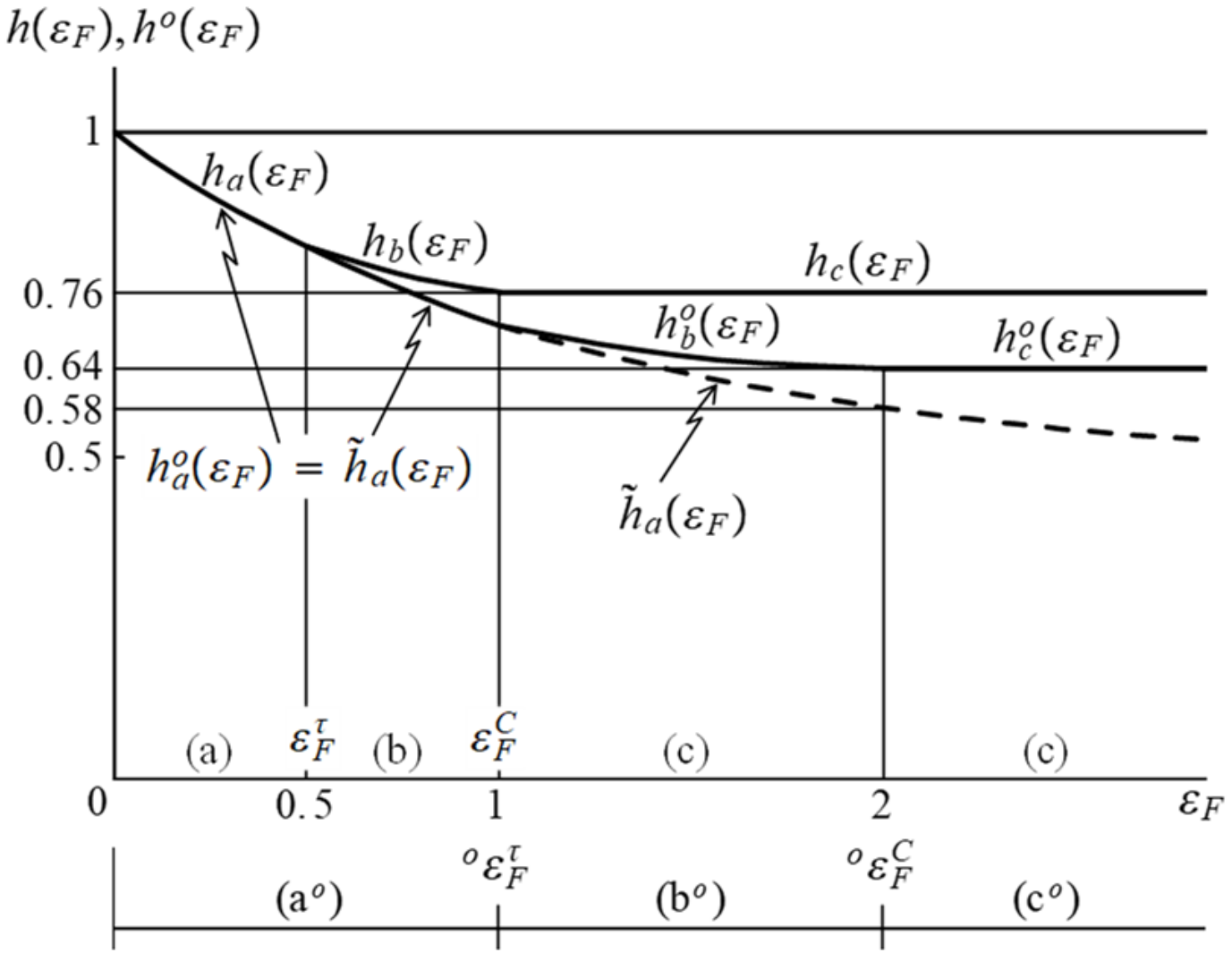


Figure 6. The impact of the advancement of net-technology on the relative productivity curve

Knowledge composition, productivity, and choice of work mode

To understand stuff graphically, it's useful to look at the symmetric states:

$$m_{ij}^d = m_{ji}^d = m^d$$

Once symmetric, always symmetric.

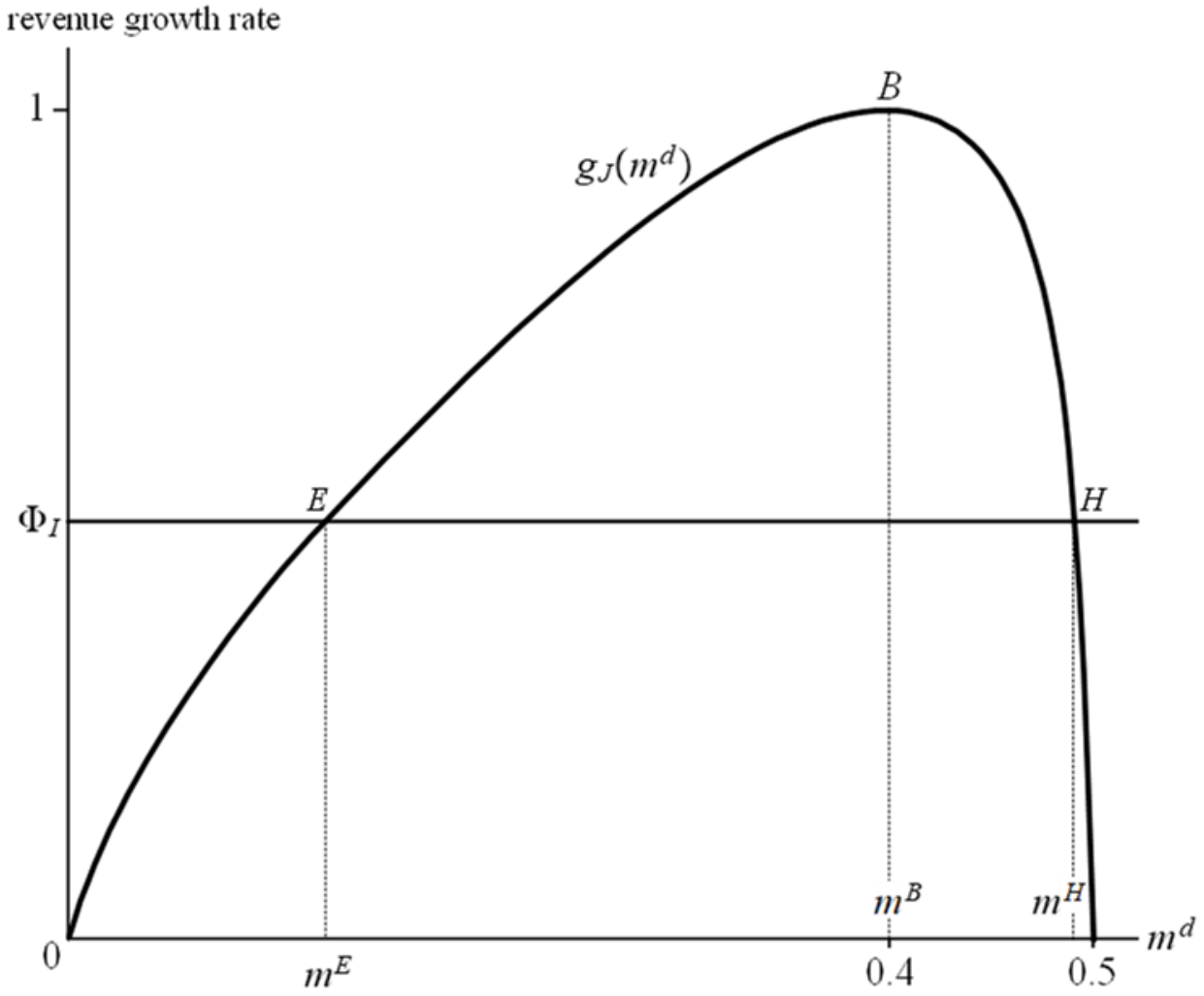


Figure 7. The knowledge growth rate curve $g_J(m^d)$ and the Bliss Point m^B.

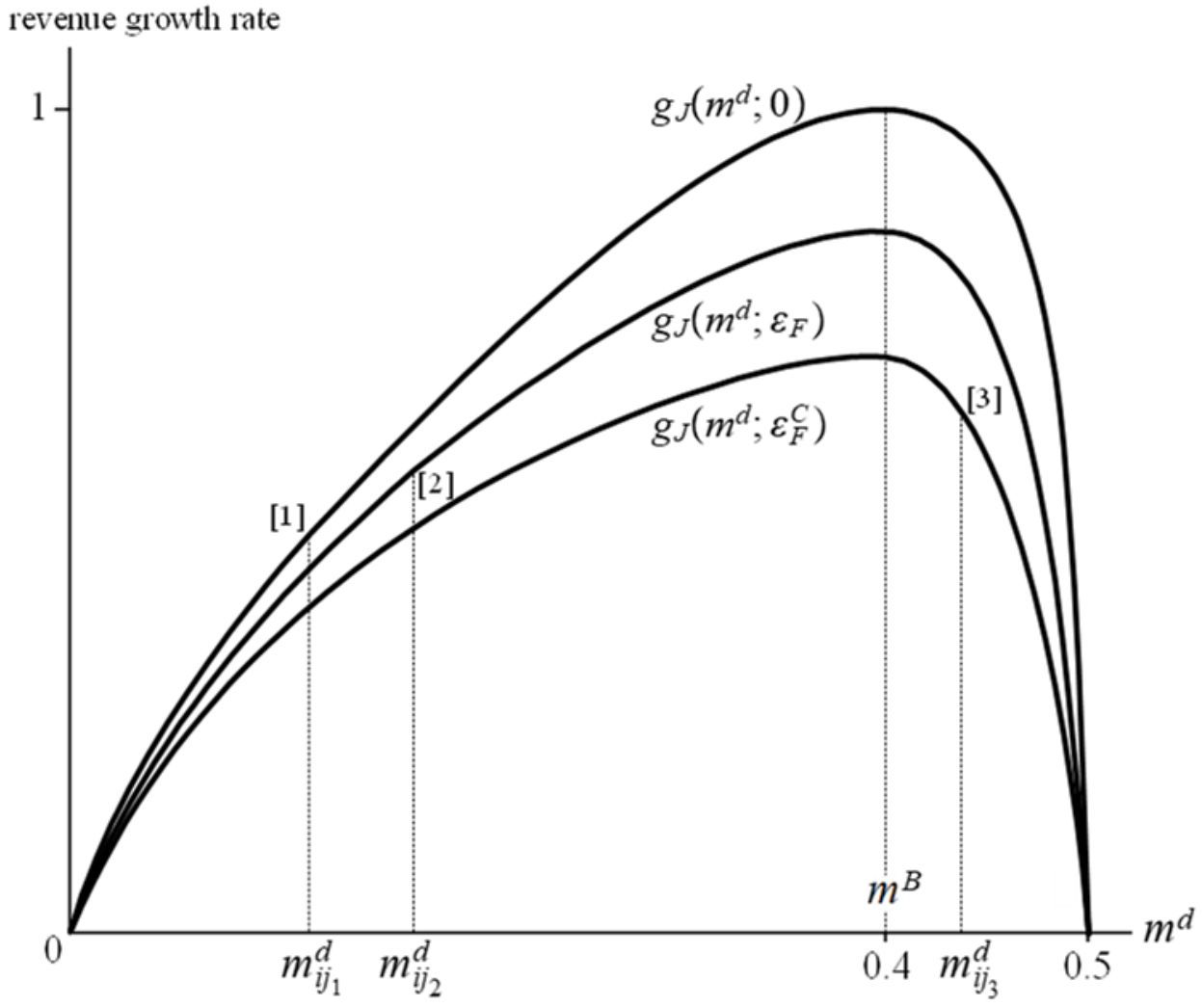


Figure 8. Knowledge growth rate curves $g_J(m^d;\varepsilon_F)$ for $\varepsilon_F = 0 < \varepsilon_F < \varepsilon_F^C$, sharing the same Bliss Point m^B, and the share of differential knowledge for each of three potential partners.

Dynamics of the two-person system

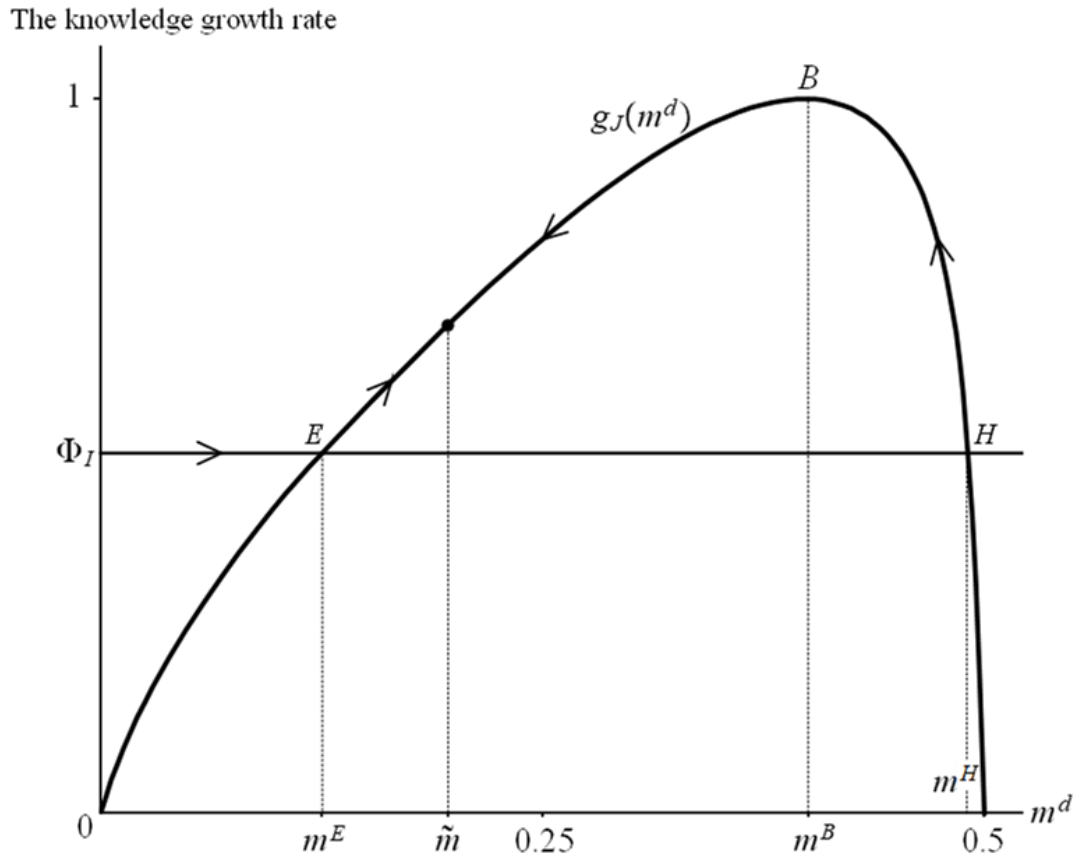


Figure 9. The dynamics of two-person system when $m^E < \tilde{m} < m^B$.

Tacit Knowledge

Next we shall define tacit knowledge and then explain how it arises in our context. The the ideas behind "tacit knowledge" originate with Polanyi (1958). Polanyi (1966, p.4) famously states, "We can know more than we can tell."

Tacit Knowledge

"...we classify human knowledge into two kinds. One is explicit knowledge, which can be articulated in formal language including grammatical statements, mathematical expressions, specifications, manuals, and so forth. This kind of knowledge can be transmitted across individuals formally and easily. This has been the dominant mode of knowledge in the Western philosophical tradition. However, we shall argue, a more important type of knowledge is tacit knowledge, which is hard to articulate with formal language. It is personal knowledge embedded in individual experience and involves intangible factors such as personal belief, perspective, and the value system. Tacit knowledge has been overlooked as a critical component of collective human behavior." Nonaka and Takeuchi (1995, p. viii)

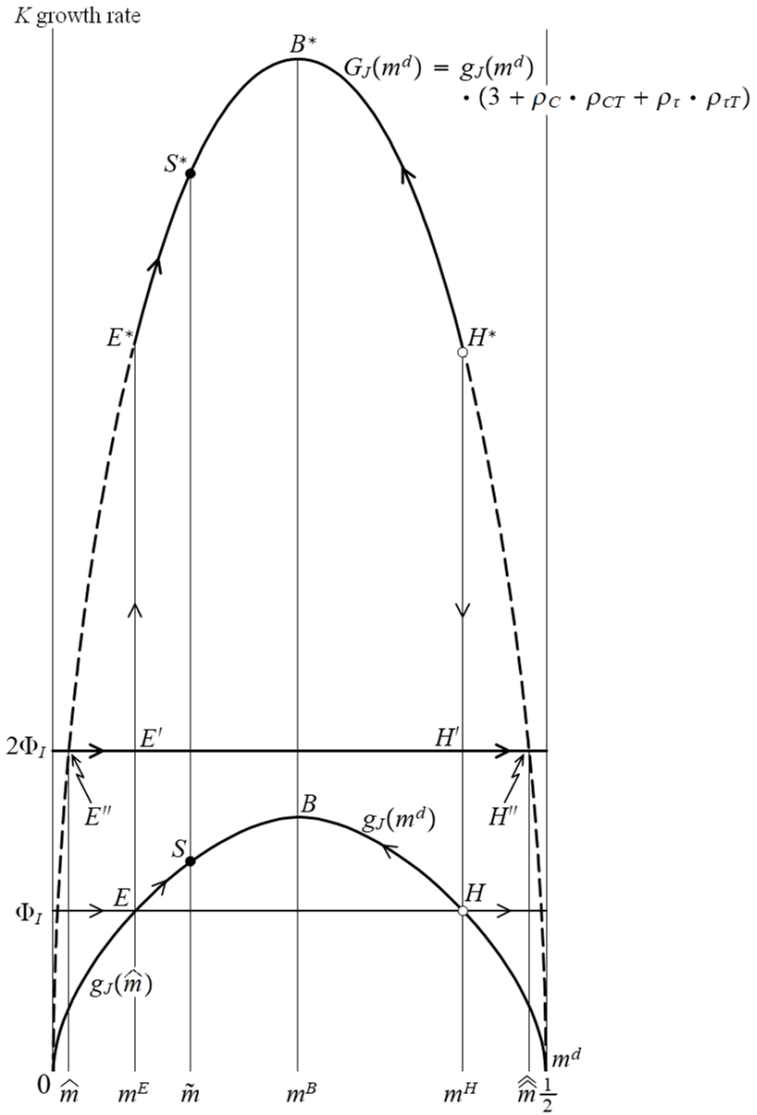


Figure 10. Dual dynamics of formal-K and total-K for the two-person system.

Inefficiency in Switch Point

- The presence of tacit knowledge causes this.

Inefficiency in Switch Point

- The presence of tacit knowledge causes this.
- The difference between the two switching rules becomes clear when we consider this situation in the context of the academic world.

Inefficiency in Switch Point

- The presence of tacit knowledge causes this.
- The difference between the two switching rules becomes clear when we consider this situation in the context of the academic world.
- An evaluation committee always faces the difficult problem of how to evaluate the contribution of each author when papers are written jointly.

Inefficiency in Switch Point

- The presence of tacit knowledge causes this.
- The difference between the two switching rules becomes clear when we consider this situation in the context of the academic world.
- An evaluation committee always faces the difficult problem of how to evaluate the contribution of each author when papers are written jointly.
- A simple, drastic rule would be that when a paper is written by 2 authors, the contribution of each author just equals one half of the contribution of the paper.

Inefficiency in Switch Point

- In the actual academic world, however, an evaluation committee tends to adopt a more generous rule.

Inefficiency in Switch Point

- In the actual academic world, however, an evaluation committee tends to adopt a more generous rule.
- That is, *if we consider efficient growth of the total knowledge of each (young) researcher in the long-run*, when a paper is written by 2 persons, the evaluation committee is justified to allocate much more than one half of the paper's contribution to each author.

Inefficiency in Switch Point

- In the actual academic world, however, an evaluation committee tends to adopt a more generous rule.
- That is, *if we consider efficient growth of the total knowledge of each (young) researcher in the long-run*, when a paper is written by 2 persons, the evaluation committee is justified to allocate much more than one half of the paper's contribution to each author.
- That is because tacit knowledge accumulates during the knowledge production process; such knowledge is invisible in the final product, namely the paper itself.

Inefficiency in Sink Point

- There is only one other potential partner, and the partners become too similar (m^d is too small).

Inefficiency in Sink Point

- There is only one other potential partner, and the partners become too similar (m^d is too small).
- This happens even if there is no tacit knowledge.

Inefficiency in Sink Point

- There is only one other potential partner, and the partners become too similar (m^d is too small).
- This happens even if there is no tacit knowledge.
- Need a Square Dance.

Summary

- Building on our earlier work, we have developed a model of knowledge creation in the context of two persons when multiple modes of communication are available, and knowledge workers can independently use the internet for the purpose of search.

Summary

- Building on our earlier work, we have developed a model of knowledge creation in the context of two persons when multiple modes of communication are available, and knowledge workers can independently use the internet for the purpose of search.
- Departing from our earlier model based on modeling knowledge creation as a *single activity*, we have elaborated the entire process of joint knowledge creation as an activity tree.

Summary

- Building on our earlier work, we have developed a model of knowledge creation in the context of two persons when multiple modes of communication are available, and knowledge workers can independently use the internet for the purpose of search.
- Departing from our earlier model based on modeling knowledge creation as a *single activity*, we have elaborated the entire process of joint knowledge creation as an activity tree.
- It has been shown that with the advancement of net technology, joint knowledge creation can be conducted over a wide range of geographical area without losing much productivity.

Summary

- Building on our earlier work, we have developed a model of knowledge creation in the context of two persons when multiple modes of communication are available, and knowledge workers can independently use the internet for the purpose of search.
- Departing from our earlier model based on modeling knowledge creation as a *single activity*, we have elaborated the entire process of joint knowledge creation as an activity tree.
- It has been shown that with the advancement of net technology, joint knowledge creation can be conducted over a wide range of geographical area without losing much productivity.
- Tacit knowledge, missing from earlier models, plays a huge role in our analysis of the dynamics of the system.

Correcting Inefficiencies

- 2 sources of inefficiency in the model

Correcting Inefficiencies

- 2 sources of inefficiency in the model
- Efficient growth of total knowledge requires that the switch from working in isolation to joint work should occur much earlier, where the growth rate of total knowledge per person in joint work is equal to the growth rate of total knowledge in isolated work.

Correcting Inefficiencies

- 2 sources of inefficiency in the model
- Efficient growth of total knowledge requires that the switch from working in isolation to joint work should occur much earlier, where the growth rate of total knowledge per person in joint work is equal to the growth rate of total knowledge in isolated work.
- To remedy the inefficiency caused by a myopic switching rule based on per capita output of patent production, a public agent may subsidize a significant portion of the revenue from patent-sales.

Correcting Inefficiencies

- Second, a more interesting and more important inefficiency is that the growth rate of formal-K at the sink point is significantly lower than at the Bliss Point.

Correcting Inefficiencies

- Second, a more interesting and more important inefficiency is that the growth rate of formal-K at the sink point is significantly lower than at the Bliss Point.
- When the research partners are in a *low-productivity sink point trap*, what possible mechanism could enable the partners to escape from this trap and attain much higher productivity?

Correcting Inefficiencies

- Second, a more interesting and more important inefficiency is that the growth rate of formal-K at the sink point is significantly lower than at the Bliss Point.
- When the research partners are in a *low-productivity sink point trap*, what possible mechanism could enable the partners to escape from this trap and attain much higher productivity?
- Answer: A modified square dance

Extensions

- It is our hope, more generally, that the model of knowledge creation through multimodal communication developed in this paper can be extended and applied in a broader context such as efficient development of international academic societies in the age of rapidly developing ICT and AI.

Extensions

- It is our hope, more generally, that the model of knowledge creation through multimodal communication developed in this paper can be extended and applied in a broader context such as efficient development of international academic societies in the age of rapidly developing ICT and AI.
- It would be of interest to allow other forms of agent heterogeneity, such as large and small city residents, or CBD and suburban residents.

Extensions

- It is our hope, more generally, that the model of knowledge creation through multimodal communication developed in this paper can be extended and applied in a broader context such as efficient development of international academic societies in the age of rapidly developing ICT and AI.
- It would be of interest to allow other forms of agent heterogeneity, such as large and small city residents, or CBD and suburban residents.
- Intergenerational transmission of knowledge and improvements in internet search productivity due to the increasing stock of knowledge over time should be investigated.

Extensions

- It is our hope, more generally, that the model of knowledge creation through multimodal communication developed in this paper can be extended and applied in a broader context such as efficient development of international academic societies in the age of rapidly developing ICT and AI.
- It would be of interest to allow other forms of agent heterogeneity, such as large and small city residents, or CBD and suburban residents.
- Intergenerational transmission of knowledge and improvements in internet search productivity due to the increasing stock of knowledge over time should be investigated.
- To sum up, there is much further work to be done to analyze the microeconomic dynamics of knowledge creation in settings with tacit knowledge and multiple modes of communication.

完

Time to sing?