The Impact of Teleworking on Firm's Organization, Urban Configuration, and Productivity

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The Impact of Teleworking on Firm's Organization, Urban Configuration, and Productivity
（組織形態、都市構造および生産性に及ぼすテレワーキングの影響）

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Chapter 1

Survey on Teleworking

Although several teleworking/telecommuting researches have explicitly argued that a continuation and accumulation of careful multi-disciplinary research on teleworking/telecommuting are important (Sato, 2013), the survey incorporating the insight from the economics is few[1]. One reason about why the research papers about teleworking/telecommuting with concrete micro-foundation are rarely mentioned, or included in those multi-disciplinary surveys is that none of these surveys are made by the economists.

We try to fill this research gap in this Chapter.

1.1 Definitions

What we really mean when we mention the term "teleworking" (or "teleworker"), poses a much more complex question than one might think at first (Salomon and Mokhtarian, 2007). How about a system consultant who works at clients' building? Is working at home after hours included? What about a freelance web designer who works at cafe? Is working occasionally once or twice a month for personal reasons at home included? How about an Indian software programmer who works at home for an American software company? And what if he works at local office? what about a housewife who uses her spare time to operate an online shop with an account in eBay at home? Few of these questions has a clear yes/no answer, which demonstrates the difficulties that we face in interpreting and reconciling the available survey data.

Several literature argued that the arbitrary use of poorly distinguished terms has be-

[1]Among others, Pontell, et al (1996), Shin, et al (2000), Tietze, et al (2009), Allen, et al (2015), Blount (2015).

come one key reason to limit consensus of the answer to most teleworking related issues (Mokhtarian, et al., 2005; Garrett and Danziger, 2007). Without ambition to integrate various definitions into one universally accepted definition, we feel necessary to introduce the basic factors/dimensions that normally constitute the definition of "teleworking", and make our own definition of "teleworking" accordingly.

1.1.1 Dimensions

We introduce in this part the dimensions that normally constitute the overwhelming majority of definitions of "teleworking".

Work locations. Normal worker and teleworker are most distinguished by where they work, or in another word how the working time is assigned among different locations, e.g. office, home, satellite office[2], field site, coffee shop (coffice[3]) or resort hotel (resort office[4]). For example, Garrett and Danziger (2007) distinguishes among three distinct forms primarily based on where they work: fixed-site teleworker (home of satellite office), mobile teleworker (field site), and flexiworker (home, office, and field site).

Contractual relationships (/coordination structures (Fritz, et al, 1995)). The relations between service provider and receiver to accomplish the specific goals is another dimension to categorize "teleworking". In theory, these activities (provide/receive services) can be coordinated by the hierarchy in one company (employer/employee relations), or by the market (contract-based B2B relations) (Malone, 1987). People can "hire" themselves and render service to other business entities through contracts, in which case we call them the self-employed[5]. To include the self-employed or not induces significant gap on definitions among literatures in different fields.

The reason is two-fold. Firstly, the self-employed itself generally include very divergent

[2]Satellite offices are "separate units within an enterprise, geographically removed from the central organization but remaining in constant communication" (Di Martina and Wirth, 1990).

[3]A survey sample made up of 1036 UK-based workers revealed that, as many as 80% of UK staff have worked 3.5 hours in average from a coffee shop every week, with 13% doing so everyday.

[4]Resort offices are hotels providing advanced communications to permit employees to work for short periods, typically one to three weeks, in pleasant locations with access to sports and leisure activities such as skiing or golf (Fritz, et al, 1995).

[5]The self-employed is a situation in which an individual works for himself instead of working for an employer that pays a salary or a wage. A self-employed individual earns his income through conducting profitable operations from a trade or business that he operates directly.

sub-types[6]: independent contractors (e.g. doctors, lawyers, accountants and a host of other professionals who own their own business; also includes contractors, subcontractors, freelance writers, auctioneers and others who provide independent services to the general public.), sole proprietors of business (small shop owners, homemaker providers, gardening service providers, etc.), and those with partnerships in business, which makes itself an elusive concept to use. Secondly, although some sub-types of self-employed do work usually at (or very closed to) where they live (e.g. small shop owners), and some sub-types of self-employed do have to work with prerequisites of physical presence (e.g. homemaker providers, gardeners, babysitters) such that the inclusion will add bias to our estimates, there are many sub-types of self-employed that belong to the most concerned worker types - broadly, we call them "information worker" or "white-collar worker" - of our research focus, such as most of the independent contractors for at least two reasons. First of all, they behave exactly like an employed senior office worker, normally seated in management except that they're the boss of themselves. Then, many of current independent contractors are substituting for a regular commute worker over the long run (Ellen and Hempstead, 2002). Hence, there are a quite reasonable basis to include part of self-employed into research subject group (Moos and Skaburskis, 2010). However, in practice, the available data normally limits our trails to include those part of self-employed.

Information and Communication Technologies (ICTs). Technology is a crucial element in the distinction between the general idea of "teleworking" and other forms of decentralized work (Sullivan, 2003). Email/IM, networked communication terminals, social networks, and new software/App[7] are allowing people to share, exchange, store, edit and access information whenever and wherever they want to do it.

However, perhaps a little surprisingly, as Blount (2015) implied that "early ("teleworking") definitions did not always explicitly mention technology, only the location of work (is mentioned)" For example, Olson's definition in 1983 only refers to the place of work: "Remote work generally refers to organizational work performed outside of the normal organizational confines of space and time." In a word, at the early stage, the term "teleworking" means mainly "remote work", not necessarily via any telecommunication technologies. In 1990s, the notion of "teleworking" gradually evolved and the necessity of distinguishing traditional homework with homework via tele-communication makes LFS in 1997 add new questions into survey

[6]The definition normally varies among the BLS, IRS.

[7]Communication: Skype, Google Docs, Google Talk, Gizmo, Line (Japan, Korea), Wechat (China), QQ (China); Presentations: GoToMeeting, LiveMeeting, WebEx, BudgetConferencing; Teamwork Live, Basecamp, ActiveCollab, CentralDesktop, QuickBase; Calendar: 30 Boxes, Google Calendar and Yahoo Calendar.

to measure - they call it - tele-homeworkers, those homeworkers who use a telephone and a computer (Felstead, et al., 2000). There are several evidences, for example since Felstead, et al (2000) which shows that around 40% homeworkers claim that they could not even do their job without both a telephone and a PC. This trend is growing since that time, more and more homeworkers do their jobs relying on the advanced ICTs appliances.

However, as Wikstrom, et al. (1997) argued that eventually technology will not relevant to the definition of “teleworking” as it will be a crucial element of most forms of work. We partially agree with the deep insight from Wikstrom, et al. (1997), but we still believe that it’s meaningful, at least currently, to distinguish those homeworkers who don’t use “PC plus Internet” , and the homeworkers who use “PC plus Internet”. We presume that the development of ICTs will have two distinguished effects on these two sub-categories: firstly, it transfers the office worker to homeworkers who use “PC plus Internet” (let’s call it E1); secondly, it transfers the homeworkers who don’t use “PC plus Internet” to whom turn to use “PC plus Internet” (let’s call it E2). The point is that we admit the existence of E2 as Wikstrom, et al. (1997) implied, meanwhile we cannot overlook the importance of E1. E2’s implication may only involve a potential efficiency gain with ITs’ aids, but E1’s implication is more complicated, because the efficiency gain or loss are both possible, and more importantly, it will have an impact on the urban transport and urban configuration, which is exactly the main research focus normally in this field.

Another issue when defining “teleworking” is whether the distinguishment of the concepts of Information Technologies (ITs) and Communication Technologies (CTs) is necessary[8]. By careful definition, it’s the CTs that facilitate the communication of the teleworkers with the supervisor, co-workers, clients, and other colleagues (the SCCCs), e.g. think about ITs as “the PC” and CTs as “the Internet”, the PC can’t help you communicate with the SCCCs remotely, unless there is Internet access. The implications are also quite different: the development of ITs encourages those workers who take on tasks which are intensive in interpersonal communication to be decentralized; on the other hand, the development of CTs encourages those workers who take on tasks which are more intensive in self-driven, self-reflection (Garicano and Rossi-Hansberg, 2006).

Frequencies. The distinction in various specific level of frequency of remote working in definition of “teleworking” is massive. The ambiguous terms like “occasionally”, “mostly”,

[8]The broad definition of ITs include CTs as well, but narrow definition of ITs doesn’t.

"primarily", "mainly" are widely used when making definitions. Besides, the different criteria about the worker with how many out-of-office workdays should be called as a typical "teleworker" never reach a consensus, e.g. from weekly criteria, such as "once per week", "2.5 days per week" or "3 days per week", to monthly criteria, such as "at least one full day per month", or even hourly criteria like "over 8 hours per week". This makes it hardly possible to try to reconcile the evidence in different literature, the survey statistics are just not comparable.

Literature normally denote the working pattern when workers fully telework as"full-time teleworking", and when workers occasionally telework as "partial teleworking". Several literature endorse that the "partial teleworking" - one or two days a week - is the most common type of teleworking (Mokhtarian, 1998). Among others, Handy and Mokhtarian (1995) found an average teleworking frequency of 1.2 days a week, or 24%. Brewer and Hensher (1996) assume a 21-workday month and yield an estimated average frequency of 22% for their 1994 sample. Varma et al. (1998) found average frequencies of 17-28% based on the data collected during 1992 to 1996 about centre-based teleworking.

Work time intervals. Workers might work from 9:00 AM to 5:00 PM at office, and work overtime after commuting back home, whether put such workers into the group of those who telework draws a line among literatures. The blurring occurs when collecting survey data, the subjects normally perceive "teleworking" as those who spend time in working at home, but don't notice whether it's within the regular 9-to-5 work time or after-work time. If the researchers want to exclude those who only work overtime at home, the definition of "teleworking" must be more specified. On the other hand, the theoretical scholars are more concerned about the substitutional relation between on-site work time (which requires commuting) and off-site work time (which doesn't require commuting) , thus they normally prefer identifying the time of "teleworking" as those where workers are no longer commuting at that day.

Examples. Choo, et al. (2005) define the teleworkers as those who're salaried employees of an organization, work at home, and use ICTs. They don't count after-work hours as teleworking, if the employee still spends a full day at the regular workplace. The frequencies are not mentioned in their definition, because the large-sample dataset they used gives no clues about how often the subjects telework.

1.1.2 Synonym of “Teleworking”

Although we use so far exclusively the term “teleworking” to refer to the broad concept that workers work out of the regular workplace (e.g. office), in literature or in mass media, there’re actually many different terms that refer to this same concept.

“Teleworking” and “telecommuting”. The term “telecommuting” is usually used interchangeably as synonym of the term “teleworking” in mass media and literatures (Blout, 2015) . However, they’re not exactly the same in the sense that, firstly, the definition of “teleworking” is normally broader than the definition of “telecommuting”, those who telecommute are normally the salaried employees of an organization, and those who telework also include the self-employed (Choo, et al., 2005). Secondly, “telecommuting” are terms consistently used in transportation literature, e.g. transport economics, etc., because transportation researchers focus on the impact upon the change of urban travel flow, such as commuting. A telecommuter is who either commutes to the office, hence produces travel need, or stay at home, hence doesn’t, whose clear transportation impacts help transportation scholars exclude those that don’t act in this binary mode, but still work out of the office. Thirdly, the European scholars prefer usage of the term “teleworking”, and the American scholars prefer usage of the term “telecommuting”. We found that the usage of “teleworking” dominates at British english context, meanwhile the usage of “telecommuting” dominates at American english context[9].

1.1.3 Our Definition

We give our definition of “teleworking” or “teleworker” in response to our specific research objective. As Sullivan (2003) argues that project-specific definitions are useful and inevitable, and the search for a universally accepted definition of “teleworking” to be used in all research in this area is challenged, to some extent unnecessary. In his words, “Such studies may not be directly comparable and this can sometimes be disadvantageous, but it seems inevitable that people will use definitions and sampling through which they can best meet the aims of their specific research”.

[9] We use the Google Books Ngram Viewer to check the frequency of the use of two groups of terms in American and British english environment. We found in books digitalized by Google Books, the frequency of the words group G_teleworker, which includes terms “teleworker”, “teleworkers”, “telework” and “teleworking” is 3.59 times more than the words group G_telecommute, which includes terms “telecommuter”, “telecommuters”, “telecommute” and “ telecommuting” in British english context in 1999, and the words group G_telecommute is 2.65 times more than the words group G_telework in American english context in the same year.

In the chapter 2 and 3, we develop economic models to explore the mechanism in what circumstances remote team is preferred to being organized by managers (organizational configurational decisions), thus we put the definition of “teleworking” in a sharp way, where workers in remote teams (or teleworkers) *never* commute, in another word, we consider full-time teleworker only.

In the chapter 4, we explore the empirical relations about whether working time at home is indeed less productive than working time at office (as we assume in the chapter 2 and 3), as the dataset we used doesn’t tell us who are identified as teleworker and how long the working time is at home, we have to make our own rule. Our rule is simple and straightforward, we identify the working time between two commuting periods as working time at office, and the others as the working time at home, including those before commuting (to the office) and those after commuting (back home). Meanwhile, our dataset just records the subject’s activities in two consecutive days, it’s truly hard for us to correctly identify further about who are teleworkers, some solid (partial) teleworkers might happen to work fully at office in our limited observation periods. Hence, we won’t draw a clear line between them in our empirical research[10].

1.2 Facts and Evidences

Several literature depict a “representative” teleworker compared to normal worker, as who’re with higher wage rate, conducting more professional/technical, manager/administrator jobs, older, male, with higher degrees, and commuting longer one-way trips to the work (Pratt, 1993; Mokhtarian et al., 1995, 2004; Drucker and Khattak, 2000; Ellen and Hempstead, 2002; Gareis, 2003).

However, others argue that the trial to depict a “representative” teleworker is futile (Bloom et al., 2014). The distribution of teleworker population is seemingly *polarized*, some teleworkers belong to the “poor” bottom group who conduct low-income *dull* (routine) tasks with low bargaining power, and some other teleworkers belong to the “rich” top group who conduct high-income *creative* (non-routine) tasks with high bargaining power. The common features between these two groups are hardly found.

Thus, the facts we found about teleworkers are critically dependent on which group we focus on, and essentially hereafter we will exclusively mainly focus on the bottom group who occupies the majority of the population, meanwhile it’s more relevant to the public issues that

[10]If one does want to draw a line in our samples, we actually identify all those who work sometimes at home as teleworkers

we are concerned about.

We highlight several key findings from the most recent reports/surveys about teleworking in the following, which describe for us the big picture of teleworking around the globe or in the specific nation, and the basic trend across the time.

First of all, the 2018 State of Remote Work Report (Global)[11], made by Owl Labs, polled 3,028 employees worldwide, represented 23 countries across 6 continents, analyzes how employees around the world think about remote work, hybrid teams, motivations for working remotely, and how learning styles affect remote teams. We highlight several key findings: Globally, (1) 44% of companies don't allow remote work at all; 16% of companies are fully remote; the residual 40% of companies are hybrid - offering both remote and in-office options; (2) the dominant reason that people choose to work remote is increased productivity/better focus, followed by the reason of no commute, then family/work-life balance; (3) The top industries represented by remote workers around the world are: Government/Education, Finance/Insurance, Technology/Marketing, Healthcare/Medical, and Manufacturing/Industrial. To conclude, more than half of companies worldwide allow remote work currently, although the heterogeneity across nations is nonnegligible, for example, in the United States, it's reported that 85% of companies were hybrid or requiring remote work, 15% of companies didn't allow remote work in 2017.

Secondly, the 2019 State of Remote Work Report (United States)[12], made by Owl Labs and Global Workplace Analytics collectively, and published in the September of 2019, gives us a fresh-new update about how the teleworking as a phenomenon is going on in the United States. We also highlight several key findings: (1) 62% of US-based employees work remotely at any frequency, among which nearly 50% of them work remotely at least once per week; (2) Small companies are 2 times likely to hire full-time remote employees; (3) The top industries represented by remote workers in the U.S. are: Healthcare (15%), Technology/Internet (10%), Financial Services (9%), Education (8%), and Manufacturing (7%); (4) The top departments represented by U.S. remote workers are: Facilities/Operations/IT (18%), Customer Service/Support/Success (15%), Sales (14%), Administrative (13%), and Executive/Company Leadership (7%).

Thirdly, the 2017 State of Telecommuting in the U.S. Employee Workforce[13], made by FlexJobs and Global Workplace Analytics told us that (1) 3.9 million U.S. employees, or 2.9

[11] https://www.owllabs.com/state-of-remote-work/2018.
[12] https://www.owllabs.com/state-of-remote-work/2019.
[13] https://www.flexjobs.com/2017-State-of-Telecommuting-US/.

percent of the total U.S. workforce, work from home at least half of the time, up from 1.8 million in 2005 (a 115 percent increase since 2005); (2) The average telecommuter is 46 years of age or older, has at least a bachelor's degree, and earns a higher median salary than an in-office worker.

Fourthly, the American Time Use Survey (ATUS)[14] released by Bureau of Labor Statistics (BLS) in the June of 2019 told us that (1) On days they worked, 82% of employed persons did some or all of their work at their workplace and 24% did some or all of their work at home; (2) Among workers age 25 and over, those with an advanced degree were more likely to work at home than were persons with lower levels of educational attainment–42 percent of those with an advanced degree performed some work at home on days worked, compared with 12 percent of those with a high school diploma and no college; (3) On days they worked in 2003, 19 percent of employed workers spent some time working while at home. The share of employed workers performing work at home rose to 24 percent in 2009, and remained relatively flat from 2009 to 2018. However, the ATUS isn't necessarily an accurate picture of teleworking overall, the reason is that it captures a lot of ad-hoc teleworking, for example including those who bring work home to finish at night. Firstly, ad-hoc teleworking is sometimes excluded from the teleworking statistics; secondly, teleworking that doesn't substitute commuting is normally outside the main focus of researchers in many fields.

Let's look at the situation in Japan, the adoption rate of teleworking is said to be considerably low (Higa and Wijayanayake, 1998; Higa and Shin, 2003) compared to other OECD/industrialized countries. This situation is quite confusing given in Japan where commuting time is generally long and the infrastructures of telecommunications are well established (Sato, 2013).

Specifically, the 2018 State of Teleworking Population Survey[15] made by Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT), published in the April of 2019 gives us big picture and basic trend of teleworking in Japan. We also highlight several key findings: (1) 29.9% of employees correctly understand the concept of teleworking (24.8% in 2017); (2) 16.6% of employees report that they once work at non-office place in the past year (14.8% in 2017); (3) 10.8% of employees report that their remote working practices are regulated and guided by some kind of teleworking programs or policies formally made by their employers (9% in 2017 and 7.7% in 2016, this statistic acts as the Key Performance Indicator (KPI) of the Japanese government's teleworking policy, by the way, the objective is to achieve 15.4% until 2020). To conclude, the state of teleworking in Japan is not that encouraging compared

[14] https://www.bls.gov/news.release/atus.nr0.htm.
[15] http://www.mlit.go.jp/crd/daisei/telework/p2.html.

to the statistic in the United states, but it's improving.

Besides, the 2019 White Paper Information and Communications in Japan made by Ministry of Internal Affairs and Communications (MIC) gives us a fresh-new update about the state of teleworking in Japan. We also highlight several key findings: (1) 19.1% of companies allow telework in 2018 (13.9% in 2017 and 9.3% in 2013); (2) 46.6% of large companies (not less than 2,000 employees) allow telework, meanwhile only 14.5% of small companies (from 100 to 299 employees) allow telework; (3) 8.7% of employees report that they once telework in the past year.

The efforts made by legislators globally are also very important in the feasibility of teleworking in the real world. For example among others, in January 10th of 2019, Rodrigo Duterte, the current President of the Philippines, signed into law a bill that allows private sector employees to "telework" or work from home, where this telecommuting/teleworking act (Republic Act (RA) 11165) aims to "promote work-life balance and address traffic congestion". Under the law, the labor department is tasked to create guidelines on the following[16]: (1) Rate of pay, including overtime and night shift differential, and other similar monetary benefits not lower than those provided in applicable laws, and collective bargaining agreements; (2) Right to rest periods, regular holidays, and special non-working days; (3) Equivalent workload and performance standards as those of comparable workers at the employer's premises, etc. Recently, a sudden "transport crisis" in Metro Manila, where one of the main railway, LTR-2, shuts down due to a fire, recalls again the local firms to reestimate the pros and cons of teleworking, and take advantage of the Act.

However, on the other hand, although the macro trend of teleworking in either developed area or developing area is quite encouraging, the recent micro cases are subtle and provoke more deep thinking about the micro mechanism of teleworking.

For example, in 2017 IBM decides to recall employees back to the office, roll back its teleworking program initiated decades ago[17]. Many analyst mentioned that IBM was losing its market advantage, and struggling to compete in the competitive tech marketplace that has become significantly more agile and nimble over the past decade. It seems that IBM blames teleworking for its market failure, hence IBM tried to rebuild its competitive advantage through literally making people work together, and hoped that it can work.

[16]https://news.abs-cbn.com/news/01/10/19/tired-of-traffic-on-way-to-office-work-from-home-bill-signed-into-law.

[17]https://www.nbcnews.com/business/business-news/ibm-tells-its-remote-employees-get-back-office-n763441.

Besides, back to 2013, Yahoo's CEO Marissa Mayer eliminated work-from-home perk[18]. Mayer said that the remote workers, who are in all divisions from marketing to engineering, simply aren't productive enough and this kinds of work-from-home arrangements popular at Yahoo were not common to other Valley companies like Google or Facebook. Interestedly, the HR boss Jackie Reeses sent out a memo, and said "Being a Yahoo isn't just about your day-to-day job, it is about the interactions and experiences that are only possible in our offices". We can observe the obsession to the proximity, here.

Another famous case study is from Google[19]. Although Google developed many remote working technologies such as Google Hangouts, Google Docs, Sheets, and Google Drive, it still insisted on continually purchasing or leasing tremendous commercial properties in the Bay area (and in the New York city), and "bussing its Silicon Valley workers in daily three-hour-plus commutes between its Mountain View HQ and San Francisco". Google said although it tested the productivity of remote teams and on-site teams and found no difference in performance, its ban on teleworking is aimed to creating company culture and preventing conspiracy.

Meanwhile, there're still many teleworking-friendly large companies. According to FlexJobs[20], who in the past 6 years ranked the 100 top companies with remote jobs, reported that there were a consistent cohort of flexible companies with remote jobs that have made the Top 100 list for the past six years[21], 23 companies made it, they include such as very famous companies Dell, ADP, Xerox and American Express, some examples of available roles in these companies include: for example in Dell, it offers work-from-home jobs like sales compensation analyst, product specialist, and senior systems engineer.

We conclude that a high heterogeneity of the attitude about teleworking among companies exists. Although the trend in aggregate is encouraging, some very famous large IT firms doubt whether teleworking program could work or not, and consider that it might have undermined, or will undermine the process of collaboration and innovation. We will try to give our own explanation about this in the Chapter 2 and 3.

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[18] https://www.sfgate.com/technology/businessinsider/article/Why-Marissa-Mayer-Told-Remote-Employees-To-Work-4304049.php.

[19] https://www.zdnet.com/article/no-telecommuting-allowed-why-is-google-investing-billions-of-dollars-in-office-buildings/.

[20] FlexJobs is an online service for professionals seeking telecommuting, flexible schedule, part-time, and freelance jobs.

[21] https://www.flexjobs.com/blog/post/companies-consistently-with-most-remote-jobs/.

1.3 Teleworking and Economics

Theoretical support is important in understanding and explaining any complex phenomenon, a lack of theoretical support can be seen in most teleworking related researches (Shin et al., 2000). Hence, in this part, although we will review both the empirical and theoretical economic studies about teleworking, we place an extra emphasis on the theoretical works.

We review the literature, issue by issue: firstly, urban travel and GHG emissions. Teleworking is normally believed to be a substitute to commuting trips, which alleviates both GHG emission and traffic congestion in metropolitan area; Secondly, urban configuration. Teleworkers are normally believed to live at outer layer of city, less burden in commuting costs enables them to live in more spacious room, this residential relocation is believed to induce undesirable "urban sprawl" - which is called "tele-sprawl" (Nilles, 1991) - and certainly, it's in debate about whether we include all teleworkers and where they live as urban residents and urban area, if we exclude them (Safirova, 2002) then the implication on urban size could be even reversed. Thirdly, productivity and work overload. Teleworking is normally believed to be either more productive or less productive lying on the type of the teleworked task, and team productivity is also as important as individual productivity, literature shows if one believes that other members in remote team are working hard, she will work hard as well.

Certainly, sometimes one literature contributes to multiple issues, we won't struggle for mentioning it just once in one place, it's all about whether it matters or not with respect to that specific issue.

1.3.1 Urban Travel and GHG emissions

Teleworking emerging as a new working arrangement firstly attracts the scholars' attentions during the first oil shock period since 1973. The booming oil price increases the burden of commuters, consequentially as well the firms' operating cost.

Jack Nilles, a former NASA engineer, proposed "telecommuting"[22] as an "alternative to transportation" in his founding document called "The Telecommunication - Transportation Tradeoff" published in the midst of the national energy crisis in 1973. Almost all research

[22] As we mentioned above, scholars who emphasize more on commuting-reducing effect of remote working are more used to calling it "telecommuting" rather than "teleworking", such as the most transportation economist, here including Jack Nilles when he firstly proposed the concept as well, but in order to keep consistency in terms we use, in this subsection we will still use the term "teleworking" except that we refer to historical facts.

focus/issues about teleworking nowadays has been mentioned by this insightful monograph 46 years ago. Although Nilles's teleworking is not quite the teleworking as we know it today after all his work was much before the advent of the Internet, the core identity of teleworking is unchanged: it will decline the energy consumption by reducing the transportation from commuting.

Since the birth of teleworking in 1970s, reductions in urban travel (mainly commuting) meanwhile GHG emissions have been the purpose of teleworking, we are not asking whether teleworking will reduce urban travel and GHG emissions or not, actually it's exactly because of the existence of these duel expected effects, Jack Nilles conceived of the concept of the so-called teleworking.

However, things are not that simple as it should be at first glance, ironically in many ways urban travel and the induced GHG emissions may unexpectedly *increase* exactly due to the introduction of teleworking.

First of all, teleworking may not reduce commute trips massively if partial, it's observed that the partial teleworking is still the primary mode until recently (Ellen and Hempstead, 2002).

Secondly, teleworking may induce "urban sprawl" - city expands to response to the decline of commuting frequency - in long term, but we can't fully identify its size or magnitude currently. On one hand, many early small-sample studies (e.g. Nilles, 1988; Hamer et al., 1991; Pendyala et al., 1991; Mokhtarian, 1991; Mokhtarian et al.,1995; Henderson et al., 1996; Mokhtarian and Varma, 1998) have established the short-run travel reduction benefits of teleworking at disaggregate level: vehicle-miles traveled (VMT[23]) are substantially reduced for those who telework, on days that they telework.

On the other hand, the problem is whether that effect scales up to a systemwide level, and whether the long-run effect offsets, or even reverse the short-run benefits (Lund and Mokhtarian, 1994; Choo et al., 2005; Larson and Zhao, 2017). Most literature found that teleworkers tend to have significantly longer commute distance than non-teleworkers (among others, Mokhtarian, et al., 1995; Collantes and Mokhtarian, 2003; Mokhtarian, et al., 2004; Ory and Mokhtarian, 2005; Zhu, 2012; Zhu and Mason, 2014), or live more likely in peripheral regions (e.g. non-metropolitan areas, suburb or rural areas, small towns, etc.) (Moos and Skaburskis, 2010).

[23]Vehicle miles of travel or vehicle miles traveled (VMT) is defined by the U.S. government as a measurement of miles traveled by vehicles within a specified region for a specified time period. The United States Federal Highway Administration (FHWA) compiles monthly and yearly VMT statistics nationally and by state.

However, simply based on these findings, then to conclude that teleworkers commute longer is misleading, at least four arguments deserve further attentions:

(1) The frequency of teleworking is an important factor. For example, Zhu and Mason (2014) compares the average VMT of non-teleworkers to the average VMT of a randomly sampled mix of teleworking days and non-teleworking days of teleworkers, only if the mix proportion of teleworking days and non-teleworking days is roughly comparable to the average frequency of teleworking of a representative teleworker, Zhu and Mason (2014)'s comparison is meaningful. Otherwise, the average VMT of teleworker will be upward (downward) biased if the sampled mix includes more data of teleworkers in non-teleworking days (teleworking days). Few literature take this consideration into account, Mokhtarian, et al. (2004) found that the longer commute one-way distance is diluted by enough less frequency of commute, consequentially the mean daily commute PMT of teleworkers is still less than the non-teleworkers.

(2) The causality issue. Teleworking causes residential relocation (to the further place away the office), or conversely long commute distance makes teleworking a more beneficial option, both direction of causality makes sense, whereas the implication is completely different. It's found that the US skilled workers are more likely to migrate long distance between states for the purpose of early career development, and once established in strong metropolitan economy catering for two jobs or careers, however, theses households are less likely to make any subsequent move (Fischer, 2000). Another tape-recorded in-depth interview out of 60 west coast US middle-class families showed that more than half represent migrants from another state. The vast majority rule out any future move which would "take them away from the neighborhood they currently identify as 'home"'. They are far more likely to accommodate changes in individual job (e.g. alternative work arrangement), school and socializing activities by "extending the volume and reach of everyday circulation" rather than "to question the permanence of their 'hub' residential location" (Jarvis, 2003). Ory and Mokhtarain (2006) uses a retrospective cross-sectional survey data, and collected the timing information about which occurs firstly, to become a teleworker, or to make a move. They found that being teleworking or not is barely an important factor into consideration when making decision to make a move, and the inferred causality from the timing of teleworking engagement and residential relocation implied that teleworking program is more like to play the role of "ameliorating the negative transportation impacts of moves that occur for other reasons" , and being teleworking or not is at most neutral to residential relocation. Collantes and Mokhtarian (2003) suggests nearly the same that "telecommuting is a consequence of a move rather than the cause of it". Kim (2016)

adopts a path analysis to explore the causality issue, one theoretical hypothesis model (THM) and one rival hypothesis model (RHM) are built, the distinction between them is to choose which two out of three crucial variables as exogenous, and leave the left one as dependent (endogenous) variable. Consequentially, the calculated goodness of fit statistics tells us that the THM, in which job and residential location are set to be independent variable to explain the teleworking choice is better fitting the data than the RHM, in which job location and the teleworking choice jointly explain the residential location. It concludes the results such that "It is likely that the majority of workers telework because of their residential/job locations even though some of them decide their locations based on their desire to telework." Moos and Skaburskis (2010) used Canadian 1996 and 2001 census data, and found that "the home workers … in non-CMA areas are less likely to have moved in the last 5 years than the wage and salary earning commuters who reside in non-CMA areas", they consequently argued that the stated immobility of home workers in non-CMA areas doesn't support the idea that alternative work arrangement leads to dispersal through household mobility. Muhammad, et al. (2007) reviewed the "other reasons" mentioned above, and concluded that the residential relocation is more related to such as the life-cycle stage of households, rather than whether or not being teleworking.

(3) Residential relocation is a decision made in household level, rather than individual level, the estimation using individual level samples will be biased. This relates to another field focusing on so-called "housing mobility". Dual wage-earner households is becoming more popular, both wife and husband's commuting demands should be considered, and respected (Jarvis, 2003). Conceptually, the estimation could be either upward or downward biased when only one of household members is teleworking: for example, in a dual wage-earner childless household, the husband is teleworker, but the wife is non-teleworker, a taken-for-granted residential location might be more closed to the wife's workplace. If so, the estimation of the impact of being teleworking on the commute trip distance (or the impact of commute trip distance on whether being teleworking) will be downward biased if their job locations are centralized (at CBD), and will be both possibly downward or upward biased if their job locations are dispersed, at least depending on firstly how far the distance between the wife's workplace and the optimal location of husband if he is alone, and secondly how closed their residential location is to the wife's workplace. It must be recognized that this job-housing specific "mismatch" flows from compromises made by households of growing internal complexity (Jarvis, 2003).

(4) Whether the commute trip distance is long or short, doesn't directly give information of residential location in the contemporary multipolar urban structure.

Thirdly, teleworking reduces commute trip, but probably increases non-commute trips, that either should have been chained into the commute trips, or is newly induced as a direct consequence of the time saved by teleworking itself (Mokhtarian, 1998). Some early literature argue that this induced increment of non-commute related travel can not be found in the survey data (Pendyala, et al, 1991; Mokhtarian, 1998), anti-intuitively, some even found that there is actually an induced "decrease", rather than "increase" of non-commute related travel (Mokhtarian, et al, 1995). On the other hand, some recent studies using large-scale travel dairy survey found the marginal effect of whether or not being teleworking on non-commute trips is significantly positive (Zhu, 2012, 2013; Kim, Choo and Mokhtarian, 2015; Kim, 2016). These analysis showed that (1) teleworkers' non-commute trips are more than non-teleworkers, although teleworker partially reduced commute trips; (2) when workers don't commute, the usual compensatory travel mechanism induces person killometers travelled of 2 km. Meanwhile among other evidences that support the idea that non-commute trips are not marginal, US national travel surveys show that in 1969 non-commute (trips) accounted for 75% of person-trips (PT) and 65% of VMT, by 2001, the shares have increased to over 85% of PT and 72% of VMT (McGuckin and Srinivasan, 2003; US Dot, 2003); typical consumer in Britain in 2006 made some 220 shopping trips with a total length 926 miles (Dft, 2006); carbon emissions of shopping trips amount to 2.7% of overall Austrian emissions, which increases by 33% until 2020 (Seebauer, et al., 2016). Unfortunately, theoretical analysis about this rebound effect is blank, we try to fill this gap in our another work using Lai-Tsai framework(Lai and Tsai, 2008).

Fourthly, even if we admit that teleworking will definitely reduce net urban travel, and thus simultaneously the induced GHG emissions from transport, the induced increase of energy consumption at home office may far exceed the induced decrease of energy consumption at traditional office. Research assessing the environmental implications of teleworking began in the late 1980s, much of the convincing work to date has only focused on the transport impacts (Mokhtarian, et al, 1995; Mokhtarian 1998; Nelson, et al, 2007). Since the late 1990s, several researchers turn to emphasize the energy implication of teleworking in a broader way, including the potential effect on commercial and residential building. Specifically, they find consistently on one hand, the induced energy use increase at home is very large, and will offset the energy saving from less commuting (Kitou and Horvath, 2003), some literatures think the net saving will be even negative (Larson and Zhao, 2017; Roder and Nagel, 2014; Matthews and Williams, 2005). On the other hand, the induced energy use decrease at office seems quite limited (Roder and Nagel, 2014; Kitou and Horvath, 2003; Mokhtarian, et al, 1995), unless the office space is shared with other employees during teleworking days (non-territorial office (Higa and Shin, 2003)), or eliminated entirely (MIAC, 2011).

Ministry of internal affairs and communications of Japan, based on a survey conducted in 2010 collecting the data of the variations of electricity consumption from ICT appliances, air conditioner, and lighting when the 16 workers assigned to the treatment group work at office, and work at home for 140 worker-days' samples in total. They found a 43.4% decline of electricity consumption from 3.8kwh/worker-day to 2.15kwh/worker-day at office, and a rise from 0kwh/worker-day to 1.12kwh/worker-day at home[24].

To summarize for analytical convenience, the impact is "direct" if the otherwise distance to commute (round-trip) is saved due to teleworking; on the other hand, the "indirect" impacts include (1) The expected increase in travel due to non-commute trip generation; (2) Longer commute distances due to residential relocation; (3) The expected increase in travel due to the additional effects of latent demand and (4) Induced demand (Mokhtaraian, 1998). The overall indirect impacts can be such substantial to wipe out all travel-reducing effect from direct impact (Mokhtaraian, 1998). It's far from having any consensus about whether teleworking will reduce urban travel and GHG emissions, things are not that naive as Jack Nilles thought when he proposed this concept in 1970s.

1.3.2 Urban Configuration

The issue about how the decline of transport cost will have impact on economic geography is widely explored since the seminal work by Krugman (1990,1991). In contrast, the studies about how the improvement of ICTs have impact on economic geography is much less and inadequate. On the other hand, as the transformation of urban configuration (e.g. households relocation, adjustment in land use) evolves much slowly and is hardly observed and identified in short term, the empirical studies contribute quite little in this issue. On the contrary, the theoretical studies are more powerful to be able to develop propositions calling for further empirical examination (Lund and Mokhtarian, 1994; Rhee, 2009).

[24]http://www.soumu.go.jp/johotsusintokei/whitepaper/ja/h23/html/nc3547c0.html.

The 1990s. Higano, Orishimo and Shibusawa's series of studies (HOS framework, hereafter) from the end of 1980s to the end of 1990s, to my best known, are the ones of the most early attempts using New Urban Economics (NUE) framework to incorporate "home work", as they call it, into studies about urban configuration and urban activities. We will briefly cover the main ideas of the three papers: Higano and Orishimo (1990), Higano (1991) and Higano and Shibusawa (1999), then roughly introduce the basic settings of the behaviors of households and firms in their framework, the details refer to the specific literature.

Higano and Orishimo (1990) applies a congestion-free open circular city of von Thunen-Alonso type model. The household weighs on time for work and leisure as well as on housing and consumption with time and budget constraint as suggested by Becker (1965), and there're two work places, such that two work types: office work in the CBD and home work. The office work consumes commuting times. The commuting times and home work exhibit utility-augmenting characteristics[25]. Besides, firms produce final goods in use of communication services and two kinds of labor, all are assumed to be traded in competitive market. The various impacts that separation of place of employment has on the suburban household behavior of residential location, time allocation, and consumption have been examined by the comparative statics analysis[26]: (i) Along with the decline of the telecommunication tariff, the demand and consequentially the wage rate of home work increases, in contrast to the decrease of the demand and consequentially the wage rate of office work, the equilibrium changes so as to make the wage rates *close* to each other; (ii) Along with the residence away from the city center, households work more at home, less at office, have more leisure time and larger residence, but consume less composite goods.

Higano (1991) applies a closed circular city of von Thunen-Alonso type partial equilibrium[27] model with Vickrey type traffic congestion (Vickrey, 1965). It develops Higano and Orishimo (1990) in a sense that it adds traffic congestion[28] into the Higano-Orishimo model and solves for specific Pigouvian tariff/subsidy that helps the city attain the Pareto-optimal one. Conceptually, as the author suggested that "the substitution (between telecommunica-

[25]As the authors suggest that "by taking account of the utilities of freshness of meeting with unknowns, we may prefer a long commute to a short one" and "communicating, as the needs arises, with one's associates in the office in the CBD provides relief and comfort" (Higano and Shibusawa, 1991).

[26]Higano (1989) provides a numerical analysis of the aforementioned impacts based on the specified utility and production functions.

[27]Higano and Shibusawa (1991) propose a general equilibrium version.

[28]The traffic congestion is widely identified as one of the primary distortion factor (with negative externality) that deviates the city at a laissez-faire equilibrium from the city at a Pareto optimum,"··· in deciding to locate in the urban areas, people ignore the congestion costs they impose on others, and the result is more people ··· than would be optimum" (Mills and De Ferranti, 1971).

tion and transport in the sense that home work comes into existence by the telecommunication and an increase in the supply of home work will decrease commuting trips) is a relief to demerits of the excessive concentration, especially to those of the traffic congestion of commuting trips", the teleworking helps alleviate distortion from traffic congestion in urban context.

Higano and Shibusawa (1999) applies a closed circular city of von Thunen-Alonso type partial equilibrium model with traffic congestion as in Higano (1991), and agglomeration economies as in Ogawa and Fujita (1980), Fujita and Ogawa (1982): the productivity of one individual firm, which is external to the individual firm and internal to the whole sector in Marshall's sense, is assumed to be positively related to the *density* of other firms around it. To be specific, as home workers won't participate in the interaction among firms in the CBD, only the employments of the *office* work count. In contrast to Higano (1991), the teleworking does help alleviate the traffic congestion but also undermines the agglomeration merit in the CBD, the trade-off between them is one primary focus. Furthermore, It also develops the previous whose analyses were confined to the spatial structure in the suburbs, in a sense that it also analyzed the spatial configuration of firms and the land assignment for transportation in the CBD[29].

Generally, the household optimization behavior is formulated as follows in the HOS framework:

$$\max_{l,T_L,T_h,T_o,T_1,T_2,x,r,z} U(l, T_L, T_h, T_o, x) \tag{1-1}$$

subject to:

$$T - T_L - T_1 - a(z,r)T_2 = 0 \tag{1-2}$$

$$bT_1 - T_h = 0 \tag{1-3}$$

$$[a(z,r) - 1]T_2 - T_o = 0 \tag{1-4}$$

$$w_1T_1 + [w_2 - 2cp_t(z,r) - t(z,r)]T_2 + d_v + D_t - p_l(r)l - p_0x \geq 0 \tag{1-5}$$

$$\eta \geq r \geq \varepsilon_c \geq z \geq 0 \tag{1-6}$$

$$l, T_L, T_h, T_o, T_1, T_2, x \geq 0 \tag{1-7}$$

Equation (1-1): function $U(x)$ is a given utility function, which positively depends on the amount of land l, leisure time T_L, the utility-augmenting part of home work T_h, commuting

[29] Read also Shibusawa (1993) and Shibusawa and Higano (1996).

time T_o, and the amount of consumption of a composite good x. Equation (1-2): the time constraint where T represents the time endowment, which is allocated to the time-consuming activities, e.g. leisure T_L, time spent in home work T_1 and time spent in office work and the derived commuting $a(z,r)T_2$. Equation (1-3): parameter b converts the actual time in home work into the utility-augmenting hours of home work. Equation (1-4): the *gross* time spent in office work $a(z,r)T_2$ equals to the *net* time spent in office work T_2 and commuting time T_o. Equation (1-5): the budget constraint where the summation of the *net* compensation from home work w_1T_1 and office work $[w_2-2cp_t(z,r)-t(z,r)]T_2$, dividends of profits by the firms d_v, and an equal redistribution (or a lump sum tax) when tax revenues are over subsidy payments (or subsidy payments are over tax revenues) must be no less than the expenditure on house $p_l(r)l$ and the composite goods p_0x. Notice the *net* compensation from office work is composed of the *gross* compensation w_2T_2 subtracting commuting cost $2cp_t(z,r)T_2$ and congestion tax charged on the supply of office work $t(z,r)T_2$, where parameter c is the reciprocal of the average time spent in office work per commuting trip, such that

$$a(r,z) = 1 + 2c\int_z^r \frac{1}{v(\xi)}d\xi$$

or

$$\frac{T_o}{2cT_2} = \frac{a(r,z)-1}{2c} = \int_z^r \frac{1}{v(\xi)}d\xi$$

where the LHS represents the time spent per one-way commuting trip, the RHS represents a cumulative time spent passing through each continuous urban ring. If the commuting velocity is constant across city (without congestion, $v(\xi) = \bar{v}$ for $\eta \geq \xi \geq 0$, and $t(z,r) = 0$), the function reduces to $T_o = 2cT_2(r-z)/\bar{v}$. Equation (1-6): households live at the suburb area between the urban boundary η and the CBD border ε_c, firms locate at the CBD. Equation (1-7): all time variables and consumption on the composite goods must be non-negative. If the firms are assumed to locate at the literal centre of city, the function further reduces to $T_o = 2cT_2r/\bar{v}$ and the equations (1-2) to (1-7) should be modified accordingly.

On the other hand, the firm (producing the composite goods x) optimization behavior is generally formulated as follows in HOS framework:

$$\max_{y_0,y_1,y_2,t_1,t_2,l_0} \Pi(z) = p_0\Gamma(z,\theta_z)F[y_0, f_1(y_1,t_1), f_2(y_2,t_2), l_0] - \sum_{i=0}^{2} p_iy_i \\ -w_1t_1 - [w_2 - s(z)]t_2 - p_l(z)l_0 \tag{1-8}$$

The firm temporarily with location at z produces using land l_0, intermediate inputs of composite goods y_0 and labor inputs of home f_1 and office work f_2 measured in "efficiency units". The inputs of home (office) work in efficiency units are a function of inputs of TYPE 1 (TYPE 2) communications services y_1 (y_2) and home (office) work in hours t_1 (t_2). The revenue also depends on a productive factor of agglomeration economies. It assumes a locational potential function $\Gamma(z, \theta_z)$, which is defined as in Ogawa and Fujita (1980), Fujita and Ogawa (1982)[30]:

$$\Gamma(z, \theta_z) = A_\Gamma \int_0^{\varepsilon_c} \int_0^{2\pi} t_2(r, \theta_r) e(r, \theta_r) \exp\{-a_\Gamma d[(z, \theta_z), (r, \theta_r)]\} d\theta_r dr \tag{1-9}$$

where $t_2(r, \theta_r)$ is the employment of office work and $e(r, \theta_r)$ is the density of the firms located at location (r, θ_r), $d[(z, \theta_z), (r, \theta_r)]$ is the distance between the firms at (z, θ_z) and (r, θ_r), it's defined as $[z^2 + r^2 - 2zr\cos(\theta_z - \theta_r)]^{1/2}$. The urban space is normally assumed to be *symmetric* such that $\partial\Gamma(z, \theta_z)/\partial\theta_z = 0$. Finally, the $s(z)$ is the subsidy paid for the input of office work in hours t_2 due to the agglomeration economies of interaction in the CBD. If there's no agglomeration economies, and hence firms are simply assumed to produce at the literal center of the city, the equation (1-8) reduces to the following as in Higano and Orishimo (1990), Higano (1991):

$$\max_{y_0, y_1, y_2, t_1, t_2} \Pi = p_0 F[y_0, f_1(y_1, t_1), f_2(y_2, t_2)] - \sum_{i=0}^{2} p_i y_i - \sum_{j=1}^{2} w_j t_j \tag{1-10}$$

Their studies exhibit several common features, some of those are what we want to generalize or extend in our thesis[31]: Firstly, most of their results critically depend on numerical simulation with doubtful specified parameters, the simulation results' validities are poorly examined and seemingly far from being general. Secondly, their research targets exclusively concentrate on deriving the *right* Pigouvian taxes/subsidies which optimally control the various external economies in the so-called information-oriented (IO, hereafter) city[32], analyze the impacts of it

[30]Strictly speaking, as urban space in Higano and Shibusawa (1999) is two-dimensional, but Ogawa and Fujita (1980), Fujita and Ogawa (1982)'s model builds on a linear city, the definition of the locational potential function in Higano and Shibusawa (1999) is more like Lucas and Rossi-Hansberg (2002).

[31]Actually, as we conclude in the following, most of the existing theoretical studies also share the same features with the HOS framework.

[32]They include various externalities from the traditional ones in urban context, e.g. agglomeration diseconomies such as the traffic congestion (Higano, 1991; Higano and Shibusawa, 1991), or agglomeration economies (Shibusawa and Higano, 1995), or the both (Higano and Shibusawa, 1999), to the teleworking-specific ones, e.g. the firms which employ teleworkers utilizes a part of housing space for production without the payment of the cost (Shibusawa and Higano, 1996), firms determine subjective optimal commuting frequency (Shibusawa, 1997).

on the spatial equilibrium of the IO city, and compare the IO city at a laissez-faire equilibrium with the IO city at a Pareto optimum. Thirdly, the market competition is perfect, complete everywhere, thus the market size, or the number of firms cannot be determined. Fourthly, firms and households are homogeneous. Fifthly, the studies as others using NUE framework assume a prior monocentric urban space. Finally, the studies with regard for agglomeration economies share with others inspired by Ogawa and Fujita (1980), Fujita and Ogawa (1982) the common defects that they exclusively focus on the *technological* externalities rather than the *pecuniary* externalities (Fujita et al., 2001).

Lund and Mokhtarian (1994) presents a very simple partial equilibrium model of residential relocation induced by teleworking, which suggests that although teleworking reduces the number of work trips, the long-term effects would probably include changes in residential location away from the workplace, thus detracting from the effect of commuting reduction. Specifically, households are located to minimize the summed cost of housing and travel, where housing cost declines, but travel cost rises as households move away from the city center. They found that, firstly the change of the least-cost location $\Delta d^* \equiv d^*(T_1) - d^*(T_0) = \ln(T_0/T_1)/k > 0$, where $T_1 < T_0$ represents the decline of the commuting frequency, and k denotes a decay constant of the land price at the metropolitan area. Secondly, the change of annual vehicle-kilometers traveled as $\Delta VKT(T_1) \equiv VKT(T_1) - VKT(T_0) = T_1 d^*(T_1) - T_0 d^*(T_0) = T_1 \Delta d^* + d^*(T_0)(T_1 - T_0)$, whose sign is inconclusive because the residential relocation effect can be so strong that the travel saving effect from teleworking is reversed. The value of this result is limited as the rent function is considered to be exogenous, and the demand side of teleworking thus the wage/income is completely missing.

Gasper and Glaeser (1998) builds a simple interaction model, in which agents freely choose the mode of interaction, and argues that telecommunication as a mode of interaction might be a *complement* rather than a *substitute* of face-to-face communication. The essence is that more effective telecommunication increases returns from new relationship, then increases the number of relationship, and some of these new relationship will end up with face-to-face contacts, this effect outweighs the substitution effect such that telecommunication plays the role as a complement of face-to-face communication if

$$\frac{R(j^*)}{R'(j^*)j^*} \frac{\int_{\alpha=\underline{\alpha}}^{\alpha^*} cT_P^*(\alpha)\phi(\alpha)d\alpha}{R(j^*)} > \frac{\alpha^*\phi(\alpha^*)T_F^*(\alpha^*)}{\int_{\alpha=\alpha^*}^{\infty} T_F^*(\alpha)\phi(\alpha)d\alpha} \frac{T_P^*(\alpha^*)}{T_F^*(\alpha^*) - T_P^*(\alpha^*)} \tag{1-11}$$

where the first term is the elasticity of the number of contacts, Gasper and Glaeser's study reminds us that the analysis exclusively focusing on remote teleworking or full teleworking, the situation in which the workers never or rarely come to the office, needs to be careful. Besides, although this study doesn't incorporate any *time* constraint explicitly, it also suggests that the leisure time might be squeezed seriously with the improvement of ICTs. Thirdly, the feasibility that telecommunication complements face-to-face communication implies that, as Leamer and Storper (2014) suggests, city will consistently play the role of the center of *interaction*, and won't be obsolete as many prognosticators predict (Toffler and Alvin, 1980).

The 2000s. Safirova (2002) nearly at the same time[33] as Higano and Shibusawa (1999) independently develops a general equilibrium model of a closed, monocentric city with the presence of teleworking, agglomeration economies and traffic congestion.

Firms produce the consumption goods under conditions of internal constant returns of scale in terms of labor and land, and of external increasing returns to scale in the total employments of the *office* work (hours) of the sector: $Z_i(x) \equiv \phi(L_t)A[(L_i^e)^\rho + a(D_i)^\rho]^{\alpha/\rho}(E_i)^{1-\alpha}$, where $L_i^e \equiv L_i[1-t(x)]$ represents the effective office work hours: commuters spend $1-t(x)$ portion of times to arrive at the office located at x, D_i represents the work hours of teleworking employed by the firm i. Besides, firms incur extra commuting costs $\tau_{c_1}(c-x)$ within the CBD when hiring the commuters, and incur extra communication costs C_c when hiring the teleworkers. Notice also that firms benefit from denser employments at the CBD: $\partial\phi(L_t)/\partial L_t > 0$, where $_t \equiv \int_0^c \sum_i L_i(x)dx$, in addition every firms at location x incur costs $C_i(x) \equiv \gamma\tau_{c_2}xZ_i(x)$ to *realize* this benefit, where γ is the number of trips to the central market made in connection with the marketing of each one unit of output, τ_{c_2}denotes the unit moving cost within the CBD. Each firm makes zero profits: $\pi = Z_i(x) - L_i(x)[w + \tau_{c_1}(c-x)] - C_i(x) - D_i(x)(w_d + C_c) - r(x)E_i(x) = 0$, where w and w_d denote wage rate of office work and telework, respectively. Firms are willing to hire teleworkers as (i) the existence of shared burden of commuting costs; (ii) $a > 0$ and the diverse labor produces more.

Households freely choose to be on-site office worker or teleworker[34]. Both types have identical utility functions: $u(x) \equiv z(x)^\lambda h(x)^\mu b(x)^v, \lambda + \mu + v = 1$, where $z(x)$ is consumption of composite goods, $h(x)$ is consumption of land, and $b(x)$ is leisure. The utility is maximized

[33] Safirova (2002) is the modified version of Safirova (1999).
[34] In equilibrium, residents are indifferent between being teleworkers and on-site office workers.

subject to time and budget constraints, for on-site office workers:

$$l(x) + b(x) + T(x) \leq H \tag{1-12}$$

$$\tau_s(x - c) + z(x) + r(x)h(x) \leq wl(x) + RI \tag{1-13}$$

where time endowment H hours are allocated to work $l(x)$, leisure $b(x)$ and commuting $T(x)$. RI represents the rental income equally distributed among all the households, and τ_s is the monetary cost per unit distance traveled. Then, for teleworkers:

$$l_d + b_d \leq H \tag{1-14}$$

$$z_d + R_A h_d \leq w_d l_d + RI \tag{1-15}$$

where teleworkers devote all their time other than leisure to telework, live at rural area and incur neither temporal nor monetary commuting cost.

The transportation inside the CBD and RD (the Residential District) is assumed to be subject to Vickrey type congestion (Vickrey, 1965). The time consumed by the commuters passing through each continuous urban ring inside the CBD and RD are given by the following:

$$t'(x) \equiv t_{gc} + \delta_c[\frac{L_a(x)}{g_2(x)}]^k \tag{1-16}$$

$$T'(x) \equiv t_{gs} + \delta_s[\frac{N_a(x)}{G_2(x)}]^k \tag{1-17}$$

where t_{gc} and t_{gs} denote the congestion-free time through each ring, $L_a(x) \equiv \int_0^x L(x)dx$ is the aggregate quantity of labor employed by the firms located at most x, $N_a(x) \equiv \int_x^s N(x)dx$ is the total number of households residing at least x, then $g_2(x)$ and $G_2(x)$ are the land devoted to roads inside the CBD and RD, respectively.

In equilibrium, the composite goods market, the land market and the labor market (for two worker types) must be clear, and the congestion tolls are imposed such that the marginal cost of putting land into roads equals the marginal benefit to commuters within the CBD and RD, respectively. The authors calibrate the model and give the numerical simulations results through (i) comparing the properties of the equilibrium configurations arising with and without the presence of teleworking; (ii) comparing the market equilibrium with the social optimal for a city with teleworking.

The authors skillfully isolate the short-term impact from the long-term impact on urban transformation using the concepts Closed City Equilibrium with population P ($CCE(P)$) and Superior Closed City Equilibrium ($SCCE$), where $SCCE \equiv max_P CCE(P)$, P is the total population of the urban area, including both office workers and teleworkers. They found (i) Wage rates, the utility level as well the total production will increase with the introduction of teleworking, and further increase in the long-run ; (ii) transport time inside CBD and RD will decline temporarily with introduction of teleworking, but rise in the long-run; (iii) CBD size and city size will shrink temporarily with introduction of teleworking, but expand in the long-run as population migrates to the city through comparing $CCE(P)$ with $SCCE$. Furthermore, for a better understanding of the total impact of teleworking (in the long-run), the authors compare the $SCCE$ evaluated by the calibrated parameters $(\rho, a, C_c) = (0.8, 0.8, 4)$ with the $SCCE$ evaluated by a group artificial parameters $(\rho, a, C_c) = (0.95, 0.9, 0.01)$, where in the artificial case the teleworker is more productive, more a substitute of office worker, and with less involved communication friction. However, they found that in the latter case wage rates as well the utility level unexpectedly decline, even if the transport time declines, total production increases and city size shrinks. The reason is because $C_c = 0.01$ is such low that nearly 60%[35] population becomes teleworkers, which tremendously undermines the agglomeration economy inside the CBD, consequentially the welfare instead falls.

Safirova's study highlights the importance of including the agglomeration-reduction effect of teleworking into the analysis, which has been widely ignored (It's true!) by the existing studies: they overwhelmingly focus on the transport-cost-reduction effect of teleworking. However, Safirova's simulation results through assuming that teleworkers have no contribution at all to the agglomeration economy at the CBD is also doubtful at least in the following two aspects: (i) quantitative effect: teleworking will release space at the CBD, which potentially accommodates more varieties (monopolistically competitive firms) with each one taking up less space ; (ii) qualitative effect: the employment at the CBD will be automatically sorting in a sense that the communication-intensive jobs stay, but the other jobs relying less on communication will leave the CBD. Both the quantitative and qualitative effects imply that with the introduction of teleworking, the agglomeration economy at the CBD won't necessarily be undermined as Safirova (2002) or Higano and Shibusawa (1999)[36] suggest.

[35]Based on the simulation results in Safirova (2002), $208491/350000 \approx 59.57\%$

[36]Higano and Shibusawa (1999) is primarily to derive the Pigouvian taxes/subsidies with congestion and agglomeration economy, rather than focus on the induced change of urban configuration with introduction of teleworking.

Rhee (2008) firstly develops formal model analyzing (home-based) teleworking in a *dispersed* job setting: production is allowed to take place everywhere in the city. This development in framework is proved to be crucial in broadening our knowledge about the teleworking as a spatial phenomenon. We regard Rhee's framework as one when the agglomeration economy is not that strong, and in contrast regard all monocentric frameworks as ones where the subject cities are zoned by the authorities (Handy and Mokhtarian, 1995), or when the agglomeration economy is overwhelmingly strong. We briefly introduce the framework used in Rhee (2008) and Rhee (2009), then highlight the implications of teleworking different with in the monocentric framework, e.g. Lund and Mokhtarian (1994), Safirova (2002).

Imagine a wedged-shaped city which is composed of eleven zones consecutively numbered from left to right, with zone 6 in the just middle, zone 1 to 5 to the left and zone 7 to 11 to the right. Each location within the same zone is treated the same with respect to transportation, residential locations and production sites. All markets are competitive, such that each agent acts as a price taker.

There are two sectors: the composite goods sector and the structure services sector. Firms produce the composite goods using labor inputs, and intermediate inputs: $X_i = E_x[M_i/(M_i + M_{hi})]^v M_i^{\mu_1} M_{hi}^{\mu_2} Y_{xi}^{1-\mu_1-\mu_2}$, where M_i and M_{hi} denote the labor inputs in man-hours of on-site work and teleworking, respectively. The term $[M_i/(M_i + M_{hi})]^v$ measures the "interaction effect"[37]: more teleworking means less interaction between workers and this works against higher productivity. Firms minimize the cost $(w_i + p_{si}s_0)M_i + w_{hi}M_{hi} + p_{xi}Y_{xi}$ to produce X_i, where M_i man-hours of on-site work require $s_0 M_i$ units of local structure services. The firms in the composite goods sector weigh space-saving merit against interaction-reducing demerit of teleworking. Moreover, firms offer the structure services using land and intermediate inputs: $S_i = E_s Q_i^{\varphi} Y_{si}^{1-\varphi}$.

A worker (i, j), who lives at zone i and works at zone j, maximizes the utility function subject to time and budget constraints:

$$\max_{x_{ij}, q_{ij}, l_{ij}, d_{ij}, h_{ij}} u_{ij} = \alpha \ln x_{ij} + \beta \ln q_{ij} + \gamma \ln l_{ij} + \eta \ln d_{ij} + \varepsilon_{ij} \tag{1-18}$$

subject to:

$$H = h_{ij} + (8 + 2g_{ij})d_{ij} + l_{ij} \tag{1-19}$$

[37]Notice that in Rhee's framework, there is only interaction of employees *within* firms, but no interaction *among* firms, which implies that there is no any positive externality from the agglomeration economy as in Higano and Shibusawa (1999), or in Safirova (2002).

$$w_{hj}h_{ij} + 8w_j d_{ij} + D = p_{xi}x_{ij} + r_i q_{ij} + 2t_{ij}d_{ij} \tag{1-20}$$

where nothing is special[38] except that the idiosyncratic taste term ε_{ij}, which are i.i.d and follow Gumbel distribution with $E_{\varepsilon_{ij}} = 0$, variance σ^2, and dispersion parameter $\lambda = 6^{-1/2}\pi/\sigma$. It reflects interhousehold variations in utility for each home-work zone pair (i, j). After all, we derive $u^*_{ij} = U_{ij} + \varepsilon_{ij}$, hence the optimal choices are described probabilistically in the form of a discrete choice model:

$$\begin{aligned}\Psi_{ij} &= Pr[u_{ij} > u_{nv} \forall (n, v) \neq (i, j)] \\ &= Pr[U_{ij} + \varepsilon_{ij} > U_{nv} + \varepsilon_{nv} \forall (n, v) \neq (i, j)]\end{aligned} \tag{1-21}$$

where Ψ_{ij} is the probability that a randomly selected consumer most-prefers commuting arrangement (i, j), then:

$$\Psi_{ij} = \frac{\exp(\lambda U_{ij})}{\sum_{nv} \exp(\lambda U_{nv})}, \sum_{i,j} \Psi_{ij} = 1 \tag{1-22}$$

The existence of this random part of utility function enables us to derive the "inclination" rather than simply the "decision" of workers about home-work zone pair (i, j), and in a sense workers simultaneously live and commute to or telework *everywhere*.

The traffic congestion is similar with the previous studies, we omit the introduction of this part, for details please refer to Rhee (2008). We finally have five market equilibrium conditions (products, structure services, on-site work, teleworking and land) and two zero profit conditions (structure services and composite goods), which are in total 7×11 equations to determine 7×11 unknowns in total: $X, S, R, p_x, p_s, w, w_h$. The authors then calibrate the model, we highlight the results different with in the monocentric framework: (i) two groups of people don't telework at all: the people living at peripheries (zone 1to 3 and zone 9 to 11) and commuting nearby, in contrast the people living at zone 6 telework massively; (ii) the employment of teleworking exclusively concentrates on the zone 6; (iii) firms at zone 6 rely the most on teleworking to avoid the high space cost, such that workers living at zone 5 commute less to the firms at zone 6 than zone 7, which breaks the conventional law of commuting: one commutes less to the distant workplace; (iv) production activity is centralized and residential activity is decentralized, *sprawl*[39] occurs; (v) most of the saved commute time is again put for more work in the form of teleworking, leisure even declines in specific parameters; (vi) the total effect on the vehicle distance traveled (VDT) is negative: the substitution effect

[38] Please refer to Rhee (2008) or Rhee (2009) for notations in detail.

[39] The idea that "the teleworking induces urban dissolution" is firstly dubbed by Nilles (1991) as "tele-sprawl".

outweighs the relocation effect given an appropriate span of parameters.

Besides, Rhee (2009) applies the exactly same model as in Rhee (2008), and examines in detail the impact on city size with the introduction of teleworking. It found that the city radius will depend on the worker interaction term, v (the city expands as the worker interaction coefficient increases), the flexibility of land use (the zoning ordinances used by some US cities expands the city scale), the space needed for home offices (the city expands if the home office requires extra space), the closeness or openness of a city (the city expands when its immigrant gate is opened), and the other fundamental forces working for centralization and decentralization of urban activities (e.g. the TFP-like term E_x, the tele-city shrinks as E_x increase, which is in stark contrast with the monocentric case where the city radius became bigger along with bigger E_x).

Rhee's studies explore the implication of teleworking in *dispersed* job setting, which highlights the necessity of reconsideration of the existing knowledge about teleworking, especially as the employment in urban area becomes more dispersed.

The 2010s. Gubins and Verhoef (2011) turns to focus on time-of-day adjustments (rather than in spatial dimension) for part-day teleworking. They apply Vickrey's dynamic bottleneck model where drivers' scheduling decisions are endogenous, in addition, driver chooses whether to be "equipped" with ICT technology that enables her to telework. It shows that marginal willingness to pay depends positively (negatively) on the number of non-teleworking (teleworking) people. (Part-day) teleworking might have an adverse marginal effect on social welfare due to the negative externality it creates: teleworkers (equipped drivers) impose higher external travel cost on other teleworkers than non-teleworkers (unequipped drivers).

Ota (2017) develops a general equilibrium model[40], and examines the impact of teleworking on household commuting patterns and on the possible influence of teleworking on household location choice and equilibrium urban structure. The model is solved analytically in linear specification with respect to commuting cost, telecommunication cost and accessibility measures.

The household who lives at x, works at x_w, maximizes the utility function $U(S_h, Z) \equiv Z$

[40]Ota (2017) is essentially the same as Ota (2011) but in more concise form. Ota (2011) assumes two kinds of firms, where the firms who hire teleworker will save in office space, in contrast workers who choose to telework have to pay for an extra space for home office. The space for home office won't increase the utility level as the space for residence by assumption. Besides, the productions are exclusively decided by the accessibility measures for both normal firms and tele-firms, the *diversity* effect implied by Safirova (2002) is assumed to be absent.

subject to $Z + R(x)S_h + T(x, x_w) = W(x_w)$, where $R(x)$ is the land rent at x and $T(x, x_w)$ is the commuting cost. The firm located at x maximizes the profit function $\Pi(x) \equiv A(x) - R(x)S - W(x)L$, where S is the lot size per firm, L is the number of workers per firm, and $A(x) \equiv \int_X a[c(x,z)]f(z)dz$ is the aggregate accessibility measure: firms produce more efficiently, $A(x)$ is higher, if locate at *denser* place. In equilibrium, the land is assigned to the agent who bids the highest, and the labor and land markets must be clear.

Owing to several simplifications as we introduced above, Ota (2017) (and Ota (2011)) successfully derive the analytical results, which is rare among others. Ota's studies found that (i) the fixed cost of teleworking, K[41], is also important in promoting teleworking, besides the reduction of the cost reduction per distance, τ; (ii) teleworkers live at the peripheral areas, tele-firm locate at the center of the city, the normal firms and the normal office workers locate at the area between, if any. Basically, agents' locations follow the order of the intensity of the relative land use.

Ota's studies firstly derive the analytical results about the land use and commuting patterns in presence of teleworking, at the expense of significant simplification of the model: the lot size and the labor input are all fixed (essentially, the Leontief production technology is applied), time constraint is out of consideration in households' optimization problem.

1.3.3 Productivity and Work Overload

In the early era (the first half of 1990s) of teleworking, it attracts managers' attentions with the (media) hype about productivity gain through working from home, where 22% productivity increase has been a conservative numbers as Nilles et al. (1976) argued, 40% around (IBM, USWest) to be the moderate, and up to 100% (double) productivity gain per teleworking occasions. The frequency of teleworking has been rising rapidly in the United States and Europe since then. However, many authors doubt this idea (Westfall, 1997; 2004), and the academic literature to date offer little satisfactory answers.

To explore this issue, at least four of the most controversial but key methodological, or measure concerns must be : Firstly, how productivity-related data is collected, by use of subjective answers of the subjects (e.g. "Yes, I think that I'm more productive in my teleworking environment than in office environment.") or through any objective identification process (Westfall, 1997; 2004)[42]? Secondly, where the productivity gains (or loss) come from? If out-

[41] Here the fixed cost means those costs, including training cost, equipment set-up costs, efficiency-reduction cost, etc., that don't depend on the commuting distance.

[42] As Westfall (1997) implied, the productivity literature relying on subjective report normally have the prob-

put is increased due to longer working time, the real productivity gain will be compromised and it will be a *pseudo* productivity gain. because in strictly speaking, the productivity gain (or loss) should be measured by output per unit working time, rather than the total output. Thirdly, is commuting time should be considered a forced cost burden for working at office, such that it should be also included and added into the normal office working hours when comparing the productivity gap. Finally, it's about the endogeneity issue, we have to think about whether the mechanism of deciding who to telework or not relies on any productivity-related factor: such as performance indicator, before we seriously consider whether teleworking itself will change the productivity of worker or not.

If we summarize the key measure concerns into one integrated equation, we have:

$$Total\ output = Working\ time\ length * Output\ per\ unit\ time \tag{1-23}$$

and thus

$$Total\ output\% = Working\ time\ length\% + Output\ per\ unit\ time\% \tag{1-24}$$

Essentially, any output gain must be either from increase in working time length, or increase in output per unit time.

The first obstacle to identify the real productivity gap, as Dutcher (2012) or Dutcher and Saral (2014) implied, can be overcome by using experimental approach. The second and third one are rarely mentioned in literature. Among exceptions, Bloom, et al. (2014) estimates this formula by using experimental data at Ctrip, a 16,000-employee, NASDAQ-listed Chinese travel agency, it found to the call center employees (subjects), home working led to a 13% performance increase, of which 9% was from working more minutes per shift, 4% from more calls per minute. It shows that most of output gain is from the increase in working time length.

Engel (2010) argues that productivity of working at home depends on relative feasibility of outside option at office and home, for example, worker at home can browse any website but worker at office can only browse work-related website, worker at home can pick up phone for personal affairs but worker at office can only pick up phone for working. Engel (2010) found that workers in a working setting with more feasible outside option do shirk more.

lem issues including the Hawthorne effects, and workers' inability to objectively gauge their own performance, teleworkers typically report higher productivity in their current environment to justify their current situation.

Furthermore, Engel (2010) found that monitoring is quite successful at reducing shirking for attainable workload (author used the term "quota"); specifically, monitoring is neutral when workload is very easy to attain; monitoring is very effective when workload is moderate; and monitoring becomes ineffective when workload is (or seemingly) unattainable. Engel's founding implies that to avoid shirking in working setting with feasible outside option, an appropriate level of workload combined with moderate monitoring will be the best solutions.

Dutcher (2012) tries to identify teleworker's productivity in creative and dull individual tasks using an experimental approach, he found that teleworking environmental effects may have positive implications (+11 to 20%) on productivity of creative tasks but negative implications (-6 to 10%) on productivity of dull tasks.

On the other hand, the task has been more often fulfilled by teamwork and rarely in single-handled context (Milliken and Martins, 1996). In Japan, the so-called "Japanese collectivism" encourages to reward or punish employees on group basis, rather than individual basis, which is historically identified as one of factors to inhibit proliferation of teleworking in Japan (Mokhtarian and Sato, 1998; Sato, 2013). This is because individual's effort will be masked in the team output, which leads to individual shirking behavior (Jones, 1984). The common managerial solution to this free-rider problem involves either direct monitoring by managers, or member monitoring in the case of self-managed teams (Erez, et al., 2002). However, this becomes substantially difficult (if not impossible) in the teleworking context, which implies a potentially output decline in team level if each individual teleworker chooses to shirk.

Dutcher and Saral (2014) explores productivity issue in teleworking team, rather than individual teleworker. They found that both teleworker's and office worker's productivity in teleworking teams are inclined to be lower than in traditional office-based team, the reason is because the belief that the teammates are working diligently is hard to be maintained due to *invisibility* of various informal, but helpful cues in traditional office-based context. More interestingly, they also found that there is no evidence supporting that teleworkers are less productive. The gap between the belief and the reality deserves attention for the management who's worried about the potential productivity gap. This evidence also told us how the productivity (in firm level, or in social level) might be undermined if the teleworking teams is improperly managed, even if there is no real productivity discount when working at home.

Besides using experimental approach, De Graaff and Rietveld (2007) uses the Dutch time use surveys (SCP, 1996; 2001), in which households were asked to keep up a diary during a week. They measure the availability of ICT using the availability of the Internet within a household. They found that working at home is paid by an implicit hourly wage rate that is 19% blow the usual wage rate when there are no Internet (in their case) present at home, when there are such facilities, the (wage rate) difference is much smaller (<3%). In the chapter 4, we're going to estimate the wage rate difference of working at home in Japan using the similar approach of De Graaff and Rietveld (2007) but using the 2006 Survey on Time Use and Leisure Activities conducted by Statistics Bureau of Japan, which covers 55,484 households and 272,861 samples in all 47 prefectures of Japan. Our dataset is larger in sample size (30 times more households than in the Dutch dataset) and more relevant (more recent data than the Dutch dataset).

1.4 Teleworking and Other Fields

Teleworking is highlighted with a truly multi-disciplinary nature. In this section, we review the literature in other fields: firm's management strategy, individual psychological status and social conventions, all these aspects imply that besides economic factors, there're many other factors that limit the proliferation of teleworking.

1.4.1 Teleworking and Knowledge Management

Teleworking is essentially related to the knowledge management strategy of firms. When firms pursue to dismiss their "office workers" to be decentralized geographically, the key element for firms to be successful is about how to accommodate this, keep "links" or "networks" active enough to fully convert each "individual knowledge" to "organizational knowledge" (Taskin and Bridoux, 2010; Peters and Batenburg, 2015). Notice nowadays, towards a globally connected world, " ⋯ the more easily codifiable (tradable) knowledge can be accessed (from anywhere), the more crucial does tacit knowledge become for sustaining or enhancing the competitive position ⋯ the fundamental exchange inability of this type of knowledge increases its importance ⋯ " (Maskell and Malmberg, 1999).

In order to discuss how teleworking plays its role, we firstly introduce the concept of "tacit knowledge". The term "tacit knowledge" is attributed to Michael Polanyi in Personal Knowledge (1958) and revived by Nelson and Winter in their classic work: An Evolutionary Theory of Technical Change (1982), furthermore it became popular in (knowledge) management studies since the middle 1990s, to a large extent, due to the publication of Nonaka and Takeuchi's The Knowledge-Creating Company (1995).

Polanyi sticks to the concept that the world's like "a map, no matter how elaborate it is, (it) cannot read itself", and stress on the "personal coefficient" if any, the knowing of "map reading" is embodied (to the person). In his words, "all knowing is personal knowing- participation through indwelling ("indwelling" means to make it be part of our body/intelligence)" (Polanyi, 1975). The decomposition of "map reading" is helpful to us because when knowledge carriers think about transferring the "ability" of "map reading", it implies that not only the "map", also the "personal coefficient" is crucial to the successful transfer. The idea is captured in the famous saying by Polanyi in his later work The Tacit Dimension (1966): "we can know more than we can tell". The discrepancy between "we can tell" and "we can know" is exactly what he called the tacit elements of "knowing". Hence, the tacit knowledge is characterized as localized, non-ubiquitous and context-specific (Gertler, 2003).

Nonaka and Takeuchi (1995) introduces it into the theory for (organizational) knowledge management, the cornerstone of it is the notion of "knowledge conversion". They propose a modal which distinguishes four modes of "knowledge conversion": from tacit knowledge to tacit knowledge (socialization); from tacit knowledge to explicit knowledge (externalization); from explicit knowledge to explicit knowledge (combination); and from explicit knowledge to tacit knowledge (internalization) (Leonard and Sensiper, 1998; Massey and Montoya-Weiss, 2006). They consider "knowledge transfer" as a spiraling interaction between "explicit knowledge' and "tacit knowledge", knowledge follows a cycle in which tacit knowledge is "extracted" to become explicit knowledge, and explicit knowledge is "re-internalised" into tacit knowledge (Nonaka and Takeuchi, 1995). Tacit knowledge, such as mental schemes and meanings of words, cannot be communicated easily through ICTs (Finhold, Sproull and Kiesler, 1990; Roberts, 2000; Pyoria, 2003), or only to the extent that they can be externalized, i.e., be "extracted" to explicit knowledge (Nodaka, 1994; Ahuja and Galvin, 2003), which is very limited.

One trade-off when concerning teleworking program: teleworking damages the "ba" (place), as Nonaka, et al. (2000) dubbed, because tacit knowledge is transferred from one subject to another in this shared social, organizational, and cultural context-office. Nonverbal behavior (contrasted to the verbal behavior), like demonstration and practice, such as in the classic master-apprentice relationship in which observation, imitation, correction and repetition are employed in the learning process (Nonaka, 1991; Gertler, 2003); extensive personal contact, regular interaction and trust generally plays an important role for effective transmission of tacit knowledge (Chugh, 2015).

1.4.2 Teleworking and Sociology

Teleworking and Border/Boundary Theory. Boundary theory focuses on the process of individual "micro" role transitions between roles. Any pair of roles (e.g. work role and home role) fall along with a continuum from high segmentation (act of partitioning) to high integration (act of overlapping). There is trade-off however, high integration of pair of roles induces negative role blurring effect, high segmented role boundaries tend to be less permeable, role transitioning between roles becomes more difficult (Ashforth, et al., 2000).

Teleworker, whose work and home roles share the same physical space, is believed to experience greater boundary blurring between work and home role, more thoughtful transitions between work and home roles are required (Fonner, et al., 2012). Many teleworkers use time (Tietze and Musson, 2003), designated home workspaces in terms of how and where they engage in certain activities, use particular equipment (Myrie and Daly, 2009; Mustafa, 2010), virtual connectivity to organization's network and intentional communication with colleagues or household members (Fonner, et al., 2012) to facilitate role transitioning process.

Teleworking and Agency Theory. The agency theory is directed at the ubiquitous agency relationship, in which one party (the principal) delegates work to another (the agent), who performs that work. A(n) "(agency) contract" is built, the theory (especially the principal-agent theory) focuses on developing the most efficient contract (Eisenhardt, 1989).

Qualitatively, there are two contract candidates: outcome-based contract (OBC) and behavior-based contract (BBC). OBC is one kind of agency contract where payment is based on whether the desired results are being achieved (e.g. payments of sales commissions or by piece work.), meanwhile BBC is another kind of agency contract where the payment is based on whether the agent appears to be performing in the manner desired by the principal (e.g. payment by hour or month). The theory consistently gives which one is preferred efficiently under varying levels of outcome uncertainty, risk aversion, information, and other contextual variables.

Hence, is OBC or BBC preferred to be teleworking contract? In words, the agency theory implies that because the difficulty of the at-home teleworkers' behavior to be observed by at-office managers, OBS is preferred than BBS. However, OBS is hardly to be efficient when (1) the task's outcome uncertainty is high; (2) the agent is more risk-averse[43]; (3) the task is more

[43] The argument behind a more risk-averse agent is that agents, who are unable to diversify their employment, should be risk-averse and principals, who are capable of diversifying their investments, should be risk-neutral (Eisenhardt, 1989).

programmed[44]; (4)the task is hardly to be measured. To summarize, teleworking programs potentially tend to transfer worker evaluations from behavior-based to outcome-based, and which hurts the efficiency sometimes.

Teleworking and Institutional Theory. The institutional theory comes from sociology and looks at the issues of organizational legitimacy. Institutions are "cultural rules giving collective meaning and value to particular entities and activities, integrating them into the larger schemes." Institutionalization is "the process by which ⋯ units and ⋯ activities come to be normatively and cognitively held in place, and taken for granted as lawful" (Meyer, Boli and Thomas, 1994). The theory argues that, although what organizations do may not be completely efficient, they conform to institutional rules that give them legitimacy (DiMaggio and Powell, 1991). By increasing its legitimacy, an organization increases its access to resources and prospects for survival (Meyer and Rowan, 1977).

The institutional theory helps us understand the low proliferation rate of teleworking. Teleworking arrangements often lack formalization (Walrave and De Bie, 2005), i.e., they are not regulated by formal policies and remain informal and individualized (Farrah and Dagen, 1993). In contrast, teleworking arrangements may be part of an organizational project, which implies preparation, formalization and communication. In the latter situation, organizations are more likely to provide formal guidelines for workers who are arranged to start to telework (Wiesenfeld et al., 1999). This formal recognition (motivated by government in some cases, e.g. Japan, California) affects how teleworkers and normal workers perceive teleworking because it increases perceived organizational support (Harris, 2003; Allen et al., 2003) as well as the social legitimacy of teleworking in the eyes of all organization (and industry) members.

Firstly, "deviant" attempt declines the survival rate. Meyer and Rowan (1977) suggests that "organizations that ⋯ create unique structures lack acceptable legitimated accounts of their activities ⋯ are more vulnerable to claims that they are negligent, irrational, or unnecessary". The office work is a highly institutionalized form which is widely perceived as legitimate; meanwhile teleworking, however, is a major deviation from the institutionalized norm of commuting to the traditional office every day. In a word, teleworking is not now considered a legitimate mode of work for most categories of employees, therefore, the organizations who adopt teleworking, include employees who work at home (which might imply less office workers, smaller office spaces) will be "more vulnerable to claims that they are negligent,

[44] Programmability is defined as the degree to which appropriate behavior by the agent can be specified in advance.

irrational, or unnecessary".

Secondly, efficiency doesn't give legitimacy. Meyer and Rowan (1977) suggests that institutionalized practices may continue even though they are in conflict with more efficient ways of performing tasks. They call it as "structural inconsistency in institutionalized organizations", for example, consider a university who must maintain appropriate departments independently of the departments' enrollments, or a sick worker who must be treated by a doctor using accepted medical procedures but whether the worker is treated effectively is less important. "categorical rules conflict with the logic of efficiency". This explains partially why teleworking proliferates slowly than expected even if it's (somehow) justified by pilot programs' results, or economic theoretical propositions that it's beneficial for all stakeholders (employers, employees and the society as a whole).

Thirdly, evaluating activities to goal achievement are always avoided by organizations. As Meyer and Rowan (1977) suggests, in order to resolve conflicts between ceremonial rules (employees commute to the office every day) and efficiency (they don't have to do that), organizations always employ two interrelated devices: decoupling and the logic of confidence. The key idea is that: the inspection, evaluation, and control of activities are minimized, and coordination, interdependence, and mutual adjustments among structural units are handled informally. For example, normally goals are made ambiguous or vacuous, and categorical ends are substituted for technical ends. Hospitals treat patients, but not cure; schools produce students, but not learning. Teleworking, however, does not yet appear to be established as an institutionalized form, with its own norms that can be accepted rather than having to rely on performance evaluation, which are always avoided by organizations.

To summarize, teleworking is poorly institutionalized such that organizations who adopt it will hardly be given legitimacy, moreover, it hurts extant legitimacy of organization through formal performance evaluation which contradicts with the decoupling strategy. It may further be viewed as lacking legitimacy because it resembles malingering (such abusing sick leave) or the socially stigmatized status of unemployment (Pontell, et al., 1996).

1.4.3 Teleworking and Media Richness Theory

Telecommunication technology is one of media which conveys information. Based on the Media Richness Theory (Daft and Lengel, 1984; 1986), they identify four dimensions to distinguish different medias from "lean" to "rich": (1) the feedback is slow or quick; (2) the channels and cues are poor or rich; (3) numeric (nonverbal) or natural (verbal); (4) customized or not (personal or impersonal). Telecommunication technologies have many kinds, such as telephone, videoconference, etc., but are all inferior to the most traditional, but richest media: Face-to-face (F2F) communication.

F2F communication "allow(s) immediate feedback so that understanding can be checked and misinterpretations corrected if the message is complex or equivocal ··· (it) also allows the simultaneous communication of multiple cues, including body language, facial expression, and tone of voice ··· (it) also is of a personal nature and utilizes high variety natural language" (Daft and Lengel, 1984).

However, although F2F communication is the richest media, it's meanwhile the most expensive media as well, in a sense that the information/knowledge carrier (human-being) must meet to have a F2F talk, the "transport" of human-being is estimated to be 5 times more expensive than cargos: the average cost of domestic business trip in the United States was $990 per day, with the average for an international trip coming in at a sizable $2525 per day[45]. Commuting costs within cities are also significant and so crucial that the variation in urban configuration (e.g. rent gradient, urban size) is massively interpreted by it.

Furthermore, Daft and Lengel (1984) critically argues that rich media is not necessarily always superior to poor media, the "poor media" may oversimplify complex problems, because these media don't transmit "the subtleties" associated with the unpredictable, personal, subjective aspects of communications. On the other hand, the "rich media" may contain surplus meaning; multiple cues can overcomplicate the communication and distract the receiver's attention from the routine, well-understood messages.

Hence, the key idea from "media richness theory" is that "···managers select media to accommodate translation needs···"to accomplish "mutual understanding/learning" Daft and Lengel (1986). Consequently, a positive relationship between media richness and message translation requirement is proposed to avoid overcomplication or oversimplification situation, which is either inefficient or ineffective.

Implications of Daft and Lengel's theory in teleworking is straightforward: in order to avoid overcomplication or oversimplification situation, managers should select workers whose tasks require high translation needs to work at office, and communicate F2F, meanwhile select workers whose tasks require low translation needs to telework (work at home).

To summarize, teleworking is justified in a sense that at least as a complementary working way, it helps manager avoid overcomplication situation to improve efficiency.

[45]Check https://www.expertmarket.com/business-travel-costs for more details about the cost level and rank of business trips.

Chapter 2

The Complementarity between Skills and Communication Technologies: Implications on the Structure of Teleworking

2.1 Introduction

The recent development of ICTs makes teleworking attract tremendous attentions in public, but what determines firms to prefer teleworking over conventional working way, or vice versa, is still unclear.

Existing literature uncover several important factors that determine firms' (or employees') preference, for example: commuting costs (Higano and Orishimo, 1990; Higano, 1991; Higamo and Shibusawa, 1999; Safirova, 2002; Ota, 2017), telecommunication technology efficiency (Gubins and Verhoef, 2011), fixed cost of teleworking (e.g. training cost, equipment set-up costs, etc.) (Ota, 2017) and so on.

In this chapter, we highlight the role of the *skill/knowledge level* of employer (manager) and employees (production workers) in firms' preference on teleworking. To our best knowledge, we're the first to do this job with concrete micro-economics foundation.

More skillful managers prefer leveraging their skill on larger team, communicating to team members to solve more problems will increase the revenue of firms, as well as their earnings. Then, we ask which form of team helps more skillful managers maximize their earnings. We introduce a (hard) constraint of managers' time for communication (Garicano, 2000): more efficient communication technology allows managers to solve more problems, namely handle larger team. Hence, There is a complementarity between managers' skill and communication technology: more skillful managers prefer more efficient communication technology.

Based on the media richness theory (Daft and Lengel, 1984; 1986), F2F communication turns out to be more efficient than telecommunication when translation requirement is high, this is exactly the situation when workers ask for managers' help to solve those unsolvable problems. Hence, more skillful managers prefer organizing conventional/normal team (NT) than teleworking team (TT).

In our model, we put income-maximizing agents (skilled and unskilled) into an urban area with the Central Business District (CBD) at origin. skilled and unskilled agents freely choose to be employees (workers) or employers (managers) or self-employed to maximize (net) income; managers decide to organize NT or TT, accordingly hire commuting workers or teleworkers; workers decide to join in NT or TT to be commuting workers or teleworkers.

One outstanding feature in our model is that decision made by one individual manager will have influence on decisions made by other managers: More managers choose to organize NT, then urban area becomes more congested, accordingly urban costs increase as well as the costs to organize NT; on the other hand, more managers choose to organize TT, then urban area becomes less congested, accordingly urban costs decrease as well as the costs to organize NT.

After all, land market and labor market clear in equilibrium, and no agent is better off through deviating from the current situation. As the results, we recognize that the force where more skillful managers prefer organizing NT than TT, and the force where if more managers decide to organize NT, less attractive it is, will combine to determine the distribution of organizational forms (NT or TT) in equilibrium.

We derive four equilibria in which (1) all agents maintain self-employed; (2) skilled agents maintain self-employed or organize NT simultaneously, meanwhile unskilled agents maintain self-employed or join in NT simultaneously; (3) all skilled agents organize NT, meanwhile unskilled agents maintain self-employed or join in NT simultaneously; and (4) skilled agents organize NT or TT simultaneously, meanwhile unskilled agents maintain self-employed, join in NT or TT simultaneously.

We also show the transformation of equilibrium in urban configuration with the change of the skill level of skilled agents. With the increase of skill level of skilled agents (from low to medium level), massive self-employed skilled agents suddenly turn to organize TT; with the further increase of skill level of skilled agents (from medium to high level), skilled agents who organize TT turn to organize NT gradually. After all, the relation between the skill level of skilled agents and ratio of the number of TT to NT exhibits an inversed "U-shape".

Our model differs from Antras, Garicano and Rossi-Hansberg (2006b) in several important aspects: (1) firstly, no urban-suburban space is specified in their model; (2) secondly, firms are organized in one way in their model, but in our model, firms are organized in two ways, one is in centralized way in the sense that the manager and the workers work together at the office, and another one is in decentralized way in a sense that the manager and the workers work separately at where they live, and get connected through the Internet; (3) thirdly, multiple forms of teams coexist in equilibrium in our model, but in Antras, Garicano and Rossi-Hansberg (2006b), the mixed equilibria emerge only in knife-edge cases, and thus ignored.

The remainder of the paper contains five sections. Section 2.2 introduces the general setups in Antras-Rossi-Hansberg-Garicano framework and Alonso-Muth-Mills model. Section 2.3 introduces our own model. Section 2.4 solves it analytically. Section 2.5 derives propositions through comparative statics. Section 2.6 makes the concluding remarks.

2.2 Framework: General Setups

2.2.1 Production in two-layer Knowledge Hierarchical Teams

In this subsection, we introduce the general setup that is common in models that build on the ARG framework. Specifically, we illustrate how production in a two-layer hierarchical teams is carried out, and how the earnings of entrepreneur is derived.

Our model builds on Antras, Garicano and Rossi-Hansberg (2006b) and Garicano and Rossi-Hansberg (2006b). They proposed a discrete version of Antras, Garicano and Rossi-Hansberg (2006a), which in turn builds on Garicano and Rossi-Hansberg (2006a) and Garicano and Rossi-Hansberg (2004), which further builds on the organizational model proposed by Garicano (2000) that exclusively focuses on *how* a product will be produced in a knowledge hierarchical structure (Antras and Rossi-Hansberg, 2008).

Agents are endowed with 1 unit of time and a skill level z, the time is either used to draw problems from the problem pool, or consumed to communicate with the subordinates to solve the problem. As in Antras, Garicano and Rossi-Hansberg (2006a), we normalize the set of problems so that the skill level z becomes also the proportion of problems an agent can solve, it's equivalent to assume that the distribution of problems is uniform over $[0, 1]$.

Suppose a two-layer team is composed of one entrepreneur with skill level z_1 and n_0 production workers with skill level z_0. The workers each spend 1 unit of time to draw a unit measure of problems, solve a fraction z_0 of problems and pass on the residual $(1 - z_0)$ to the entrepreneur's layer, then the entrepreneur solves a fraction $(z_1 - z_0)$ of problems. Hence, in total the hierarchical team as a whole solve $n_0 z_1$ problems.

The output of the team is measured by how many problems are solved by the team, we use y to denote the output of the team, and meanwhile we treat the "solved" problem as the numeraire, thus y represents the revenue of the team as well.

$$y = n_0 z_1 \tag{2-1}$$

Production is accomplished whenever either workers or the entrepreneur solve the problems, so y can be decomposed into two portions:

$$y = \underbrace{n_0 z_0}_{Solved\ in\ Worker's\ Layer} + \underbrace{n_0(z_1 - z_0)}_{Solved\ in\ Entrepreneur's\ Layer} = n_0 z_1 \tag{2-2}$$

The size of team is limited by the time endowment of agents. Suppose the entrepreneur spends h_0 units of time in communicating with her subordinates for each problem, no matter if she knows the solution to the problem or not, thus in total each entrepreneur spends $n_0 h_0 (1 - z_1)$ units of time to address problems.

On the other hand, since each entrepreneur is endowed with 1 unit of time, we have the time constraint of the entrepreneur as given by

$$n_0 h_0 (1 - z_0) \leq 1 \tag{2-3}$$

where the LHS of equation (2-3) represents the demand of the time of the entrepreneur, and the RHS of it represents the supply of the time of the entrepreneur, equation (2-3) says that the demand can not exceed the supply.

Denote the wage of production workers by w_0. The entrepreneur is assumed to absorb all the operating profits of the firms, thus the earnings of the entrepreneur is given by

$$w_1 = y - n_0 w_0 = n_0(z_1 - w_0) \tag{2-4}$$

From equation (2-4), the entrepreneur will use up her time endowment to maximize her span of control, which equals the team size n_0, and thus

$$n_0 = \frac{1}{h_0(1-z_0)} \tag{2-5}$$

where higher z_0, and/or lower h_0 will increase the span of control of the entrepreneur.

Substitute n_0 into equation (2-4), we have

$$w_1 = \frac{z_1 - w_0}{h_0(1-z_0)} \tag{2-6}$$

apparently, the entrepreneurs, as earnings maximizer, are motivated to enlarge her span of control.

2.2.2 Rent Curve and Commuting Costs

In this subsection, we introduce the general setup and implications that are common in models that build on the Alonso-Muth-Mills model (AMM model, hereafter), for years which has been the workhorse in urban economics[1]. Specifically, we illustrate how agents are distributed around a prior Central Business District (CBD), how land rents at each location are derived and how the urban cost for urban residents is defined in small closed urban model.

Suppose a linear space $[0, +\infty)$, where a prior CBD is located at the origin. At each location, 1 unit of land is supplied inelastically and all lands are assumed to be owned by the absentee landowners. Each unit of land is heterogenous solely in terms of the distance to the CBD.

For illustrative convenience, suppose further that there are homogeneous agents whose population is set to be P. Each agent is assumed to consume exact 1 unit of land, and choose consumption on a composite good, which is set as the numeraire, to maximize the utility level.

The utility function is given by $u = c(x)$, where $c(x)$ represents the consumption level on the composite good for agents who reside at x units of distance to the CBD.

Agents work for the firms at the CBD, earn wage income w, but pay for commuting cost by themselves, which is distance-dependent cost in a sense that for the agent living at the location with x units distance to the CBD, the agent pay τx for commuting trips, where τ represents the commuting cost per unit distance. Then, we have the budget constraint of the

[1]See Glaeser (2008) for details.

agent at location x as

$$w = r(x) + \tau x + c(x) \tag{2-7}$$

The most important concept in AMM model is the spatial equilibrium, it says that for homogeneous agents, whatever location she lives at, as she is freely moving from one location, say x, to another location, say x', it has to be indifferent for her. As the choice of x and x' is arbitrary, thus we have

$$\frac{dc(x)}{dx} = 0 \tag{2-8}$$

We then denote this distance invariant consumption (utility) level as c. Then, we substitute c back into equation (2-7), we have

$$w = r(x) + \tau x + c \tag{2-9}$$

The bid rent function is thus derived as

$$r(x) = w - c - \tau x \tag{2-10}$$

where the bid will be declining along with the distance to the CBD increases.

To close the model, we must solve for c. This is usually done by assuming that there are some alternative uses of land which generate rents of r_A, and this will naturally be the rent level at the city edge. We denote $\overline{x}$ as the boundary location such that $r(\overline{x}) = r_A$.

To derive $\overline{x}$, we use the land market clearing condition: P residents who each use 1 unit of land must use P units of land, thus P must equal $\overline{x}$, then we have

$$r_A = r(\overline{x}) = w - c - \tau\overline{x} = w - c - \tau P \tag{2-11}$$

then we derive c explicitly

$$c = w - r_A - \tau P \tag{2-12}$$

which is obviously increasing in w and decreasing in r_A, τ and P.

2.3 Model

In this section, we build our own model, in which firms at the CBD are organized in 2-layer knowledge hierarchical structure. Two types of firms are considered, one we call it as in normal firm such that the employees are obliged to commute to the CBD, and another one we call it as in teleworking firm such that the employees are not obliged to commute to the CBD. We dub the employees at normal firms and teleworking firms as normal workers and teleworkers, respectively.

Besides, two types of agents are introduced, one we call it as the skilled agents with knowledge level z_H, and another one we call it as the unskilled agents with knowledge level z_L, where we assume throughout $z_H > z_L$.

We introduce the basic settings firstly, then uncover the behaviors of the skilled and the unskilled agents in order, thirdly we give several conditions that must be satisfied in equilibrium, fourthly we solve it analytically and derive propositions through the comparative statics.

2.3.1 Basic Settings

Suppose that the economy is inhabited by P units of population with H units of skilled agents, and L units of unskilled agents, where $H + L = P$.

For NTs, we presume that both entrepreneurs and normal workers are obliged to commute to the CBD, the communication friction is inhibited to the minimal level as face-to-face (F2F) communication is normally regarded to be the most efficient way to exchange information. With the regard we concern now, the information exchange involves that the normal workers ask for the entrepreneur's help to solve the unsolved problems, and the entrepreneur answers to the normal workers.

In contrast, for TTs, we presume that both entrepreneurs and teleworkers are not obliged to commute to the CBD[2], they will work at the place where they live, namely at each residence respectively. The communication friction is relatively higher than in NTs as communication remotely through E-mail, phones and/or video call all involve more inevitable misunderstandings that are evitable when communicating F2F.

Therefore, we denote h_N and h_T to represent the time units consumed for each single problem in NTs and TTs, respectively, and where we assume throughout $h_N < h_T$.

Let's start from the analysis of the matching and sorting problem of the skilled agents. Potentially, the skilled agents are allowed to become entrepreneurs or production workers in either type of teams. However, we prove in the following that the skilled agents will never

[2]With an increasing number of organizations encouraging teleworking, it's common to see organizations (e.g. AT&T, Deloitte, Ernst&Young) where both the supervisor and the subordinate telework (Raghuram and Fang, 2014).

become production workers, the result is concluded in the Lemma 2.3.1, and the proof is given in the Appendix.

Lemma 2.3.1 *The skilled agents are never motivated to be production workers in either type of teams.*

Hence, the skilled agents will either choose to become entrepreneurs to organize NTs or TTs, or choose to work on their own to become self-employed.

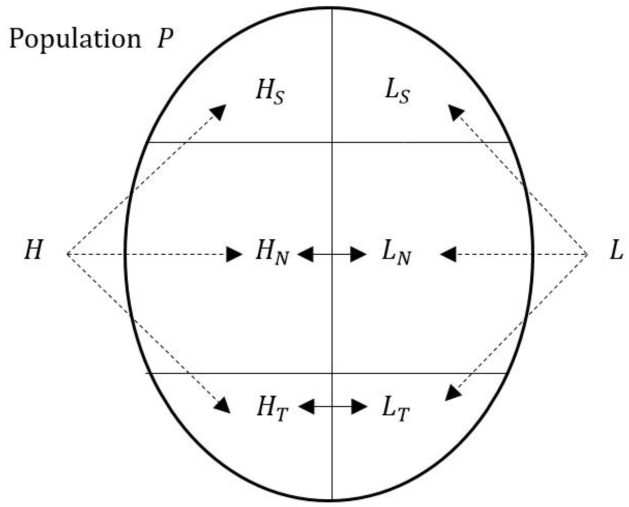

Figure 2.1: Matching and sorting patterns (the single arrows with dotted line imply sorting patterns; the double arrows with solid line imply matching patterns)

Then, we turn to the analysis of the matching and sorting problem of the unskilled agents. Potentially, the unskilled agents are also allowed to become entrepreneurs or production workers in either type of teams. However, we prove in the following that the unskilled agents will never become entrepreneurs, the result is concluded in the Lemma 2.3.2, and the proof is given in the Appendix.

Lemma 2.3.2 *The unskilled agents are never motivated to be entrepreneurs in either type of teams.*

Hence, the unskilled agents will either choose to become production workers to serve at NTs or TTs, or choose to work on their own to become self-employed.

In conclusion, we have

$$L_N + L_T + L_S = L \tag{2-13}$$

$$H_N + H_T + H_S = H \tag{2-14}$$

where we denote the aggregate amount of production workers in NTs, TTs and being self-employed by L_N, L_T and L_S, similarly the aggregate amount of entrepreneurs in NTs, TTs and being self-employed by H_N, H_T and H_S, respectively (see Figure 1).

2.3.2 Behavior of the Skilled Agents

As we show in the Lemma 2.3.1, the skilled agents are never motivated to be production workers, thus the choice is between to be entrepreneurs, or to maintain self-employed, and if the skilled agents decide to be entrepreneurs, then choose which type of teams, NT or TT, to organize.

Besides, the skilled agents also enter into local land auction market, they compete with the unskilled agents, as well with the other skilled agents.

Strategic Interactions. By our settings, the strategies, that is to organize NT, TT or be self-employed, of other skilled agents other than, say agent $i \in \{1, 2, \ldots, H\}$, play a non-trivial role on agent i's strategy, we formally construct a game structure, and treat the equilibrium in Nash style: no one benefits from *unilaterally* deviating from current situation.

Let (A^H, u) be a game with H players/agents where the A^H is the set of strategy profile, the strategy set is symmetric where $A \equiv \{N, T, S\}$. And $u(a) = (u_1(a), \ldots, u_H(a))$ is its payoff function evaluated at $a \in A^H$. Let a_i be a strategy for skilled agent $i \in \{1, 2, \ldots, H\}$ and let a_{-i} be a strategy profile (a vector of strategies) for all skilled agents other than i. When each skilled agent i chooses strategy a_i resulting in strategy profile $a = (a_1, a_2, \ldots, a_H)$, then skilled agent i obtains payoff $u_i(a)$.

Payoff Functions. We assume $u_i = c_i$, where c_i denotes the consumption of a composite good of agent i, which is set to be the numeraire, namely the payoff is derived solely from the consumption level, as we show in the following, which turns out to be further derived through subtracting expenditures on commuting trips and residence from gross income.

We firstly introduce how the gross income is determined , then introduce how the commuting cost and land rent are determined.

Let w_H^N, w_H^T and w_H^S be the gross income offered at the market for skilled agents when organize NT, TT and maintain self-employed, respectively.

$$w_H^N(a) = \frac{z_H - w_L^N(a)}{h_N(1 - z_L)} \tag{2-15}$$

$$w_H^T(a) = \frac{z_H - w_L^T(a)}{h_T(1 - z_L)} \tag{2-16}$$

and

$$w_H^S = z_H \tag{2-17}$$

where $w_L^N(a)$ and $w_L^T(a)$ represent the wage expenditure per normal worker and teleworker evaluated at $a \in A^H$, respectively. One outstanding feature in our model is that the occupational decisions of the skilled agents affect the wage expenditure on the unskilled agents, meanwhile the wage expenditure per normal worker and telework conversely affect the occupational decisions of the skilled agents as well.

For simplicity, we won't distinguish the expenditures on the land and the residence, in a sense agents reside at "bare" land. Thus, all the expenditures on the residence for agents will just equal to the land rent. Presume the land rent function as $r(x; a)$, where x denotes the distance to the CBD. Let c_H^N, c_H^T and c_H^S be the utility (consumption) level derived by the skilled agents who organize NT, TT and maintain self-employed, respectively.

$$c_H^N(x; a) = w_H^N(a) - \tau_H x - r(x; a) \tag{2-18}$$

$$c_H^T(x; a) = w_H^T(a) - r(x; a) \tag{2-19}$$

and

$$c_H^S(x; a) = w_H^S - r(x; a) \tag{2-20}$$

where by our settings, only the skilled agents who decide to organize NTs are obliged to commute to the office in the CBD, τ_H denotes the commuting costs per unit distance.

2.3.3 Behavior of the Unskilled Agents

The unskilled agents are never motivated to be entrepreneurs, thus the choice is between to be production workers, or to maintain self-employed, and if the unskilled agents decide to be production workers, then choose which type of teams, NT or TT, to join in.

Besides, the unskilled agents also enter into local land auction market, they compete with the skilled agents, as well with the other unskilled agents.

The problem about the behavior of the unskilled agents is much simpler than the skilled agents'. Let c_L^N, c_L^T and c_L^S be the utility (consumption) level derived by the unskilled agents

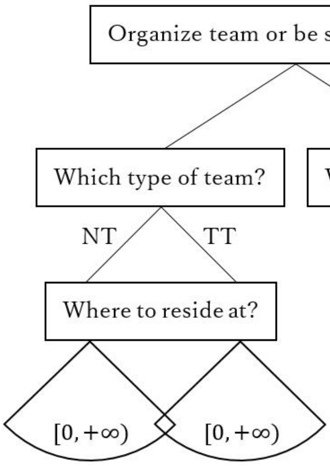

Figure 2.2: The decision tree of the skilled agents

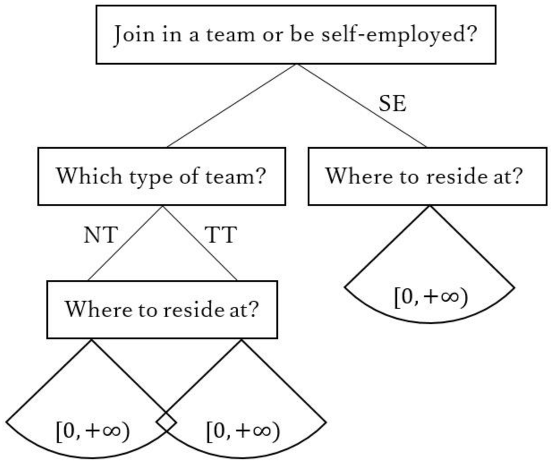

Figure 2.3: The decision tree of the unskilled agents

who join in NT, TT and maintain self-employed, respectively:

$$c_L^N(x;a) = w_L^N(a) - \tau_L x - r(x;a) \tag{2-21}$$

$$c_L^T(x;a) = w_L^T(a) - r(x;a) \tag{2-22}$$

and

$$c_L^S(x;a) = w_L^S - r(x;a) \tag{2-23}$$

where by out settings, only the unskilled agents who decide to join in NTs are obliged to commute to the office in the CBD, $\tau_L \leq \tau_H$[3] denotes the commuting costs per unit distance.

2.4 Equilibrium

In this subsection, we firstly give the equilibrium conditions that must be satisfied in equilibrium, then give the algorithm. then clarify in detail about how to derive a in equilibrium, which is the key to solve the whole system.

2.4.1 Equilibrium Conditions

In this subsection, we introduce conditions that must be satisfied in equilibrium, namely they include: the spatial equilibrium condition, the free cross-occupational mobility condition, the land market clearing condition and the labor market clearing condition.

[3]We assume $\tau_L \leq \tau_H$ to avoid the emergence of extreme case that we're not interested in.

Spatial Equilibrium Condition. First of all, the one most important concept in AMM model is the spatial equilibrium, in our specific context, it says that for each category of agents, as they are freely moving from one location, say x, to another location, say x', it has to be indifferent for them to reside at x, or x'. Thus we have for each category of skilled agents

$$\frac{dc_H^N(x;a)}{dx} = 0, \frac{dc_H^T(x;a)}{dx} = 0 \; and \; \frac{dc_H^S(x;a)}{dx} = 0 \tag{2-24}$$

meanwhile for each category of unskilled agents

$$\frac{dc_L^N(x;a)}{dx} = 0, \frac{dc_L^T(x;a)}{dx} = 0 \; and \; \frac{dc_L^S(x;a)}{dx} = 0 \tag{2-25}$$

This further implies that for each category of agents, there is a location invariant utility level for all $x \in [0, +\infty)$:

$$c_H^N(x;a) = c_H^N(a), c_H^T(x;a) = c_H^T(a) \; and \; c_H^S(x;a) = c_H^S(a) \tag{2-26}$$

$$c_L^N(x;a) = c_L^N(a), c_L^T(x;a) = c_L^T(a) \; and \; c_L^S(x;a) = c_L^S(a) \tag{2-27}$$

Substitute equations (2-26) and (2-27) back into equations (2-18) to (2-23), we have for each category of skilled agents

$$c_H^N(a) = w_H^N(a) - \tau_H x - r(x;a) \tag{2-28}$$

$$c_H^T(a) = w_H^T(a) - r(x;a) \tag{2-29}$$

and

$$c_H^S(a) = w_H^S - r(x;a) \tag{2-30}$$

meanwhile for each category of unskilled agents

$$c_L^N(a) = w_L^N(a) - \tau_L x - r(x;a) \tag{2-31}$$

$$c_L^T(a) = w_L^T(a) - r(x;a) \tag{2-32}$$

and

$$c_L^S(a) = w_L^S - r(x;a) \tag{2-33}$$

Free Cross-occupational Mobility Condition. In this subsection, we return back to the individual analysis, by definitions it's straightforward to show that for any skilled agent $i \in \{1, 2, \ldots, H\}$:

$$c_i(a_i, a_{-i}) = c_H^{a_i \in A}(a) \tag{2-34}$$

literally, the payoff of any skilled agent i who chooses a_i given a_{-i} is equal to the payoff of the representative agent in group labeled a_i, which is the common strategy that all the group members choose, given a. In another word, notice that the LHS measures payoff in individual level, and the RHS measures payoff in group level, thus it's just saying that the payoff of individual equals the common payoff of individuals in group.

We claim that a strategy profile $a \in A^H$ is a Nash equilibrium (NE) if

$$\forall i, a_i' \in A : c_i(a_i, a_{-i}) \geq c_i(a_i', a_{-i}) \tag{2-35}$$

that is a situation where for any single skilled agent, it's not profitable to unilaterally deviate to change strategy, for example, transform organizational form from NT to TT, or dismiss the team (NT or TT) and turn to work on her own.

On the other hand, with respect to the unskilled agents, similarly with the skilled agents, they freely choose to be self-employed, or join in either NT or TT. However, the unskilled agents simply choose the work that gives them the highest payment.

Assumption 2.4.1 $\frac{H}{L} < h_N(1 - z_L)$.

where the Assumption 2.4.1 is saying that the ratio of the skilled agents to the unskilled agents in the economy is less than the ratio of the entrepreneur to the production workers in NTs. We derive the Lemma 2.3.3 then, and the proof is given in the Appendix. Intuitively speaking, as one single skilled agent will hire the most unskilled agents if the skilled agents decide to organize NTs, thus the most unskilled agents will be hired if all skilled agents decide to organize NTs. The Lemma 2.3.3 is saying that, even if all skilled agents decide to organize NTs, there will still be a portion of residual unskilled agents who end up with being self-employed.

Lemma 2.4.1 *If the Assumption 2.4.1 holds, there will be always a portion of unskilled agents who maintain self-employed.*

We therefore argue that in equilibrium, whatever in NTs or TTs, the payment on the unskilled agents (minus the urban costs in NTs) won't be higher than the earnings of being self-employed, otherwise the entrepreneur can always offer the self-employed unskilled agents a marginally higher wage rate to hire them, the self-employed unskilled agents will receive the offer as long as it's higher than the earnings of being self-employed. Meanwhile, whatever in NTs or TTs, the payment on the unskilled agents (minus the urban costs in NTs) won't be less than the earnings of being self-employed either, otherwise the employed unskilled agents can always leave to become self-employed. Therefore, we have under the free cross-occupational mobility condition, the utility (consumption) level will be constant across working patterns. We denote $c_L(a)$ as this constant level then we have

$$c_L(a) \equiv c_L^N(a) = c_L^T(a) = c_L^S(a) \tag{2-36}$$

Land Market Clearing Condition. In equilibrium the land market should be cleared: the supply of land equals the demand of land. Specifically by our settings, 1 unit of land is supplied inelastically to the market at each location x. The land is assigned to the agents through an auction market, the bidder who bids the highest obtains the land. We call the function that gives the highest bid that each category of agents want to offer at each location x as the bid rent function.

Literally, the highest bid the agents are willing to offer will equal to the residual income after subtracting expenditures on commuting trips (if necessary) and consumptions from the gross income, thus we have that for each category of skilled agents the bid rent functions are given by

$$r_H^N(x;a) \equiv w_H^N(a) - c_H^N(a) - \tau_H x \tag{2-37}$$

$$r_H^T(a) \equiv w_H^T(a) - c_H^T(a) \tag{2-38}$$

and

$$r_H^S(a) \equiv w_H^S - c_H^S(a) \tag{2-39}$$

meanwhile for each category of unskilled agents the bid rent functions are given by

$$r_L^N(x;a) \equiv w_L^N(a) - c_L^N(a) - \tau_L x \tag{2-40}$$

$$r_L^T(a) \equiv w_L^T(a) - c_L^T(a) \tag{2-41}$$

and

$$r_L^S(a) \equiv w_L^S - c_L^S(a) \tag{2-42}$$

where the agents in TTs, and the self-employed will offer a location invariant bid, meanwhile the agents in NTs will bid higher along with being closed to the CBD.

The market rent curve turns out to be an envelope curve of all bid rent curves:

$$r(x;a) = \max\{r_H^N(x;a), r_H^T(a), r_H^S(a), r_L^N(x;a), r_L^T(a), r_L^S(a)\} \tag{2-43}$$

We firstly argue that the agents in TTs, and the self-employed won't bid higher than r_A, the reason is because given the gross wage income offered at the market, any bid higher than r_A will just decline the utility (consumption) level but no any extra benefit exists at all. Meanwhile, by the definition of r_A, the bid rent can not be lower than r_A either. Hence, the bid rent of the agents in TTs and the self-employed will equal r_A.

As the agents in TTs, and the self-employed will only bid the lowest, any bid with premium will bid over them. The equation (2-42) thus turns to be

$$r(x;a) = \max\{r_H^N(x;a), r_L^N(x;a)\} \tag{2-44}$$

Therefore, the land market clearing conditions are given by

$$H_N = |\{x \in [0, +\infty) | r_H^N(x;a) > r_L^N(x;a) > r_A\}| \tag{2-45}$$

$$L_N = |\{x \in [0, +\infty) | r_L^N(x;a) > r_H^N(x;a) > r_A\}| \tag{2-46}$$

where the RHS of equation (2-45) represents the total amount of locations where the skilled agents in NTs bid over the unskilled agents in NTs, the RHS of equation (2-46) represents the total number of locations where the unskilled agents in NTs bid over the skilled agents in NTs.

If the LHS is larger than the RHS, it implies that there will be remaining agents who're not assigned to any location, if the RHS is larger than the LHS, it implies that there will be remaining bidden locations who're not assigned to any agent. In equilibrium, these inconsistencies must vanish.

Labor Market Clearing Condition. In equilibrium the labor market should be cleared: the supply of labor (at each category) equals the demand of labor (at each category).

We firstly argue that the labor market of the skilled agents is always cleared, the reason is because they essentially "offer" jobs to themselves, thus there is no discrepancy between the supply and demand:

$$H_N = |\{i \in \{1, 2, \dots, H\}|a_i = N\}| \tag{2-47}$$

$$H_T = |\{i \in \{1, 2, \dots, H\}|a_i = T\}| \tag{2-48}$$

and

$$H_S = |\{i \in \{1, 2, \dots, H\}|a_i = S\}| \tag{2-49}$$

where the total amount of skilled agents who chooses a_i directly gives H_{a_i}.

Then, we focus on the labor market of the unskilled agents. There is clear demand and supply side with respect to the unskilled agents. Firstly, the skilled agents who organize NTs and TTs hire corresponding type of production workers in a fixed proportion, which is derived from the time constraint of the entrepreneurs:

$$L_N^d = \frac{H_N}{h_N(1 - z_L)} \tag{2-50}$$

$$L_T^d = \frac{H_T}{h_T(1 - z_L)} \tag{2-51}$$

where L_N^d and L_T^d represent the demands of normal workers and teleworkers, respectively.

On the other hand, the supply is from the unskilled agents who choose to join in NTs and TTs. We denote them as L_N^s and L_T^s, respectively. Then, we have that the unskilled labor market is cleared if the demand equals the supply:

$$L_N = L_N^s = L_N^d \textit{ and } L_T = L_T^s = L_T^d \tag{2-52}$$

2.4.2 Algorithm

We solve the model analytically following the algorithm blow:

1. Derive $c_L^N(a)$ and $c_H^N(a)$. Use $r_L^N(\bar{x}; a) = r_A$ and $r_L^N(H_N; a) = r_H^N(H_N; a)$, where $x = H_N$ denotes the boundary between which the residential areas of skilled and unskilled agents in NTs locate at, we have

$$c_L^N(a) = w_L^N(a) - \tau_L(H_N + L_N) - r_A \tag{2-53}$$

$$c_H^N(a) = w_H^N(a) - \tau_H H_N - \tau_L L_N - r_A \tag{2-54}$$

where as further $L_N = L_N^d = H_N/[h_N(1-z_L)]$, we have

$$c_L^N(a) = w_L^N(a) - \tau_L H_N[1 + \frac{1}{h_N(1-z_L)}] - r_A \quad (2\text{-}55)$$

$$c_H^N(a) = w_H^N(a) - \tau_L H_N[\frac{\tau_H}{\tau_L} + \frac{1}{h_N(1-z_L)}] - r_A \quad (2\text{-}56)$$

2. Derive $w_L^N(a)$ and $w_L^T(a)$. The unskilled agents in TTs and the self-employed unskilled agents bid equally r_A, meanwhile as $c_L(a) = c_L^N(a) = c_L^T(a) = c_L^S(a)$, thus we have

$$w_L^N(a) = z_L + \tau_L H_N[1 + \frac{1}{h_N(1-z_L)}] \quad (2\text{-}57)$$

$$w_L^T(a) = z_L \quad (2\text{-}58)$$

where the wage premium to hire normal workers is derived as

$$w_L^N(a) - w_L^T(a) = \tau_L H_N[1 + \frac{1}{h_N(1-z_L)}] \quad (2\text{-}59)$$

which is increasing in τ_L and H_N, that is to say: the existence of more NTs will make marginally organizing an additional NT less attractive.

3. Derive a, in another word H_N, H_T and H_S (see the equations (2-47) to (2-49)). We explain in detail about how to derive a blow.

4. Substitute a (or H_N) back into equations, and derive $L_T = H_T/[h_T(1-z_L)]$, $L_S = L - L_N - L_T$ and the other variables.

Entrepreneurs' Trade-offs. We define $\Delta c_H^{a_i a_j}(a) \equiv c_H^{a_i}(a) - c_H^{a_j}(a)$ where $a_i, a_j \in A = \{N, T, S\}$ but $a_i \neq a_j$ as the payoff differential of the entrepreneurs between any pair of strategies, thus we have for example

$$\begin{aligned} \Delta c_H^{NT}(a) &= c_H^N(a) - c_H^T(a) \\ &= [w_H^N(a) - \tau_H H_N - \tau_L L_N] - [w_H^T(a) - r_A] \\ &= r_A[1 + \frac{1}{h_N(1-z_L)}] + \frac{(z_H - z_L)(1 - h_N/h_T)}{h_N(1-z_L)} \\ &\quad -\tau_L H_N\{[\frac{1}{h_N(1-z_L)}]^2 + 2[\frac{1}{h_N(1-z_L)}] + \frac{\tau_H}{\tau_L}\} \end{aligned} \quad (2\text{-}60)$$

where the entrepreneur prefers organizing NT over TT if $\Delta c_H^{NT} > 0$, and prefers organizing TT over NT if $\Delta c_H^{NT} < 0$.

Furthermore from now on, we assume that the opportunity cost of the land is equal to zero such that $r_A = 0$, it's easy to show that this additional assumption won't change any qualitative result in our model.

Then, we identify two opposing effects that describe the trade-off faced by the entrepreneur in decision of organizational forms:

$$\Delta c_H^{NT}(a) = \underbrace{\frac{(z_H - z_L)(1 - h_N/h_T)}{h_N(1 - z_L)}}_{The\ Span-of-control\ Effect} - \underbrace{\hat{\tau}(\tau_H, \tau_L)H_N}_{The\ (Urban)\ Congestion\ Effect} \tag{2-61}$$

where

$$\hat{\tau}(\tau_H, \tau_L) \equiv \tau_L\{[\frac{1}{h_N(1 - z_L)}]^2 + 2[\frac{1}{h_N(1 - z_L)}] + \frac{\tau_H}{\tau_L}\} \tag{2-62}$$

and the former effect is normally positive, hence inhibits teleworking, and the latter effect is normally negative (considering the minus sign "-" in front of this term), and hence promotes teleworking.

Notice that the "Span-of-control Effect" is increasing to z_H, which implies that the entrepreneur with higher skilled level will be more likely to organize NTs. It echoes with the recent trend that several leading IT giants, like IBM, are calling thousands of their teleworkers back into the office, despite given the growing numbers of the Americans working from home elsewhere (GWA and Flexjobs, 2017). The reason is very simple in our framework, it's exactly from the *complementarity* between the communication technology and the entrepreneurs' skill level: more skillful entrepreneurs prefer more advanced communication technology to leverage their superior skill on a larger team.

Besides, we have $\Delta c_H^{NS}(H_N)$ and Δc_H^{TS}

$$\Delta c_H^{NS}(H_N) = \frac{(z_H - z_L)[1 - h_N/\hat{h}(z_H, z_L)]}{h_N(1 - z_L)} - \hat{\tau}(\tau_H, \tau_L)H_N \tag{2-63}$$

where

$$\hat{h}(z_H, z_L) \equiv \frac{z_H - z_L}{z_H(1 - z_L)} \tag{2-64}$$

and

$$\Delta c_H^{TS} = z_H[\frac{\hat{h}(z_H, z_L)}{h_T} - 1] \tag{2-65}$$

Entrepreneurs' Strategy Profile in Equilibrium. In this subsection, we derive the strategy profile a, in which no one wants to deviate from the current strategy to the other feasible ones.

In the following, the discussion follows two steps, firstly we imagine the world when the tele-communication friction is prohibitively high ($\Delta c_H^{TS} < 0$); secondly, we discuss the case when the tele-communication technology is improved such that TTs become feasible ($\Delta c_H^{TS} > 0$).

Firstly, by the equation (2-65) we have $\Delta c_H^{TS} < 0$ is equivalent to suppose $h_T > \hat{h}(z_H, z_L)$, the entrepreneur will be always worse off through deviating from strategy S to T: in another word, S is a dominant strategy in terms of T as long as $h_T > \hat{h}(z_H, z_L)$. Thus, in any Nash equilibrium, no one will choose strategy T: $H_T = 0$, then either strategy N or S will be adopted by skilled agents.

We explore three situations and argue that they're Nash equilibria within specific area of parameters. First is when $H_N = H$ and $H_S = 0$, apparently it's a Nash equilibrium if no agent is marginally better off through deviating from N to S unilaterally, for any agent i it holds if

$$c_i(N, a_{-i}) \geq c_i(S, a_{-i}) \tag{2-66}$$

where specifically

$$a_{-i} = (\underbrace{N, \ldots, N}_{H-1\ in\ total}) \tag{2-67}$$

Use the equation (2-34) and the definition of $\Delta c_H^{NS}(H_N)$, we have the condition (2-66) is equivalent to

$$\Delta c_H^{NS}(H_N = H) \geq 0 \tag{2-68}$$

Second is when $H_N = 0$ and $H_S = H$, apparently it's a Nash equilibrium if no agent is marginally better off through deviating from S to N unilaterally, for any agent i it holds if

$$c_i(N, a_{-i}) \leq c_i(S, a_{-i}) \tag{2-69}$$

where specifically

$$a_{-i} = (\underbrace{S, \ldots, S}_{H-1\ in\ total}) \tag{2-70}$$

Use the equation (2-34) and the definition of $\Delta c_H^{NS}(H_N)$, we have the condition (2-69) is equivalent to

$$\Delta c_H^{NS}(H_N = 0) \leq 0 \tag{2-71}$$

However, as

$$\Delta c_H^{NS}(H_N = 0) = \frac{(z_H - z_L)[1 - h_N/\hat{h}(z_H, z_L)]}{h_N(1 - z_L)} > 0 \tag{2-72}$$

the situation when $H_N = 0$ and $H_S = H$ will never be a Nash equilibrium: the self-employed will be always better off through deviating to organizing NT.

Third is an interior equilibrium when $H_N > 0$ and $H_S > 0$, we denote H_N^{NS} such that it satisfies the following equation

$$\Delta c_H^{NS}(H_N = H_N^{NS}) = 0 \tag{2-73}$$

where H_N^{NS} is the level that makes agents just indifferent to be self-employed or organize NTs. Say if there is any agent who deviates from S to N, then H_N will increase, Δc_H^{NS} turns negative as $\partial \Delta c_H^{NS}/\partial H_N < 0$, thus no benefit to be explored through deviation. On the other hand, say if there is any agent who deviates from N to S, then H_N will decrease, Δc_H^{NS} turns positive, thus in the same way no benefit to be explored through deviation. To conclude, the situation when $H_N = H_N^{NS}$ and $H_S = H - H_N^{NS}$ will be a Nash equilibrium as neither unilateral deviation will make that agent better off.

This situation emerges if neither conditions that induce corner equilibrium hold, as $\Delta c_H^{NS}(H_N = 0) > 0$ always holds, we only require that

$$\Delta c_H^{NS}(H_N = H) < 0 \tag{2-74}$$

We derive H_N^{NS} as

$$H_N^{NS} = \frac{(z_H - z_L)[1 - h_N/\hat{h}(z_H, z_L)]}{\hat{\tau}(\tau_H, \tau_L)h_N(1 - z_L)} \tag{2-75}$$

Secondly, by the equation (2-65) we have $\Delta c_H^{TS} < 0$ is equivalent to suppose $h_T < \hat{h}(z_H, z_L)$, the entrepreneur will be always worse off through deviating from strategy T to S: in another word, T is a dominant strategy in terms of S as long as $h_T < \hat{h}(z_H, z_L)$.

Thus, in any Nash equilibrium, no one will choose strategy S: $H_S = 0$, then either strategy N or T will be adopted by skilled agents.

Similarly, we explore three situations and argue that they're Nash equilibria within specific area of parameters. First is when $H_N = H$ and $H_T = 0$, apparently it's a Nash equilibrium if no agent is marginally better off through deviating from N to T unilaterally, for any agent i it holds if

$$c_i(N, a_{-i}) \geq c_i(T, a_{-i}) \tag{2-76}$$

where specifically

$$a_{-i} = (\underbrace{N, \ldots, N}_{H-1\ in\ total}) \tag{2-77}$$

Use the equation (2-34) and the definition of $\Delta c_H^{NT}(H_N)$, we have the condition (2-76) is equivalent to

$$\Delta c_H^{NT}(H_N = H) \geq 0 \tag{2-78}$$

Second is when $H_N = 0$ and $H_T = H$, apparently it's a Nash equilibrium if no agent is marginally better off through deviating from T to N unilaterally, for any agent i it holds if

$$c_i(N, a_{-i}) \leq c_i(T, a_{-i}) \tag{2-79}$$

where specifically

$$a_{-i} = (\underbrace{T, \ldots, T}_{H-1\ in\ total}) \tag{2-80}$$

Use the equation (2-34) and the definition of $\Delta c_H^{NT}(H_N)$, we have the condition (2-79) is equivalent to

$$\Delta c_H^{NT}(H_N = 0) \leq 0 \tag{2-81}$$

However, as

$$\Delta c_H^{NT}(H_N = 0) = \frac{(z_H - z_L)[1 - h_N/h_T]}{h_N(1 - z_L)} > 0 \tag{2-82}$$

the situation when $H_N = 0$ and $H_T = H$ will never be a Nash equilibrium: the skilled agents who organize TT will be always better off through deviating to organizing NT.

Third is an interior equilibrium when $H_N > 0$ and $H_T > 0$, we denote H_N^{NT} such that it satisfies the following equation

$$\Delta c_H^{NT}(H_N = H_N^{NT}) = 0 \tag{2-83}$$

where H_N^{NT} is the level that makes agents just indifferent to organize TTs or organize NTs. Say if there is any agent who deviates from T to N, then H_N will increase, Δc_H^{NT} turns negative as $\partial \Delta c_H^{NT} / \partial H_N < 0$, thus no benefit to be explored through deviation. On the other hand, say if there is any agent who deviates from N to T, then H_N will decrease, Δc_H^{NT} turns positive, thus in the same way no benefit to be explored through deviation. To conclude, the situation when $H_N = H_N^{NT}$ and $H_T = H - H_N^{NT}$ will be a Nash equilibrium as neither unilateral deviation will make that agent better off.

This situation emerges if neither conditions that induce corner equilibrium hold, as $\Delta c_H^{NT}(H_N = 0) > 0$ always holds, we only require that

$$\Delta c_H^{NT}(H_N = H) < 0 \tag{2-84}$$

We derive H_N^{NT} as

$$H_N^{NT} = \frac{(z_H - z_L)[1 - h_N/h_T]}{\hat{\tau}(\tau_H, \tau_L)h_N(1 - z_L)} \tag{2-85}$$

Summary. To conclude, we derive four equilibria in which (1) all agents maintain self-employed; (2) skilled agents maintain self-employed or organize NT simultaneously, meanwhile unskilled agents maintain self-employed or join in NT simultaneously; (3) all skilled agents organize NT, meanwhile unskilled agents maintain self-employed or join in NT simultaneously; and (4) skilled agents organize NT or TT simultaneously, meanwhile unskilled agents maintain self-employed, join in NT or TT simultaneously. We denote them as E_S, E_{NS}, E_N and E_{NT} in order.

Specifically, if $h_T \geq \hat{h}(z_H, z_L)$: E_S emerges if $h_N \geq \hat{h}(z_H, z_L)$; whereas if $h_N < \hat{h}(z_H, z_L)$: E_{NS} emerges if

$$\hat{\tau}(\tau_H, \tau_L)H > \frac{(z_H - z_L)[1 - h_N/\hat{h}(z_H, z_L)]}{h_N(1 - z_L)} \tag{2-86}$$

E_N emerges if

$$\hat{\tau}(\tau_H, \tau_L)H \leq \frac{(z_H - z_L)[1 - h_N/\hat{h}(z_H, z_L)]}{h_N(1 - z_L)} \tag{2-87}$$

If $h_T < \hat{h}(z_H, z_L)$: E_N *also* emerges if

$$\hat{\tau}(\tau_H, \tau_L)H \leq \frac{(z_H - z_L)(1 - h_N/h_T)}{h_N(1 - z_L)} \tag{2-88}$$

E_{NT} emerges if

$$\hat{\tau}(\tau_H, \tau_L)H > \frac{(z_H - z_L)(1 - h_N/h_T)}{h_N(1 - z_L)} \tag{2-89}$$

We draw a figure in $(\lambda, \hat{\tau}H)$ space to highlight the area within which each equilibrium emerges (see Figure 4), where $\lambda \equiv 1/h_T$ represents the telecommunication efficiency:

Notice in Figure 2.4, the position of the areas of E_N (pure NTs), E_{NT} (a mix of NTs and TTs) implies that in order to accommodate/breed[4] more TTs, the congestion (implied by $\hat{\tau}H$) is necessary but not sufficient, the induced increase in communication friction in organizing

[4]Sometimes, the government is motivated to promote teleworking due to the reasons out of our current model setting, e.g. improve the employment rate of the disabled, the female, etc.

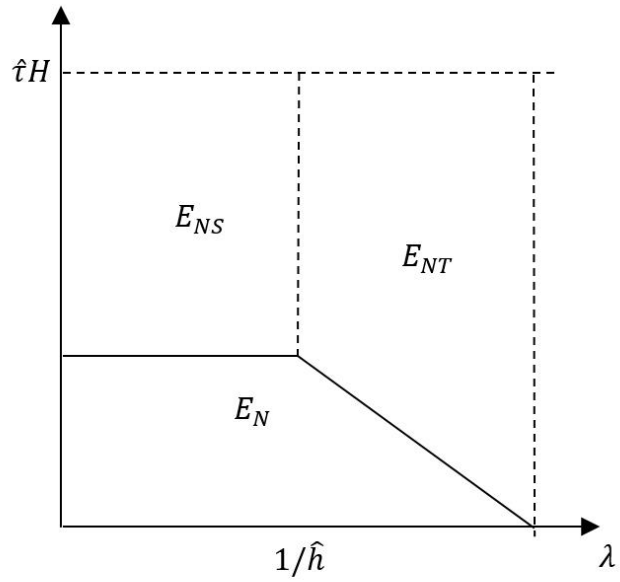

Figure 2.4: The Equilibrium if $h_N < \hat{h}(z_H, z_L)$

TTs ($h_T > h_N$) must be somehow inhibited to make it stable in equilibrium.

Besides, as we show in the following (the Proposition 2.5.1), we found that the skill levels z_H of the skilled agents *also* play an important role in entrepreneurs' decisions about the organizational forms.

2.5 Comparative Statics

In this subsection, we derive propositions about the impact of the skill levels (z_H and z_L) of the agents on the organizational forms and the urban size, meanwhile we also explore the implications when the urban population grows proportionally.

2.5.1 Effects of the Skill Level of Skilled Agents

Notice that as $\partial\hat{h}/\partial z_H = z_L/[(1-z_L)z_H^2] > 0$ and $\partial\hat{\tau}/\partial z_H = 0$, the Figure 2.5 exhibits how the equilibrium evolves if the skill level of the skilled agents z_H increases. The result is concluded in the Proposition 2.5.1.

Proposition 2.5.1 *The production in the city composed of the skilled agents with higher z_H will be (i) more likely to be organized in pure NTs; (ii) less likely to be organized in the mixed way of NTs and the self-employed; furthermore (iii) less likely to be organized in the mixed* *way of NTs and TTs if $\overline{\hat{\tau}H}$ is sufficiently low:*

$$\overline{\hat{\tau}H} < (z_H - z_L)(1 - \frac{h_N}{\hat{h}})[\frac{1}{2}(\frac{z_H}{z_L})(\frac{\hat{h}}{h_N} - 1) + 1] \tag{2-90}$$

The Proposition 2.5.1 is saying that the "Span-of-control Effect" (see equation (2-61)) in micro level does have similar implication in macro level: the skilled agent with higher skill level prefers organizing NT compared to TT, the city with skilled agent with higher skill level is also more likely to be organized in pure NTs compared to a mix of NTs and TTs.

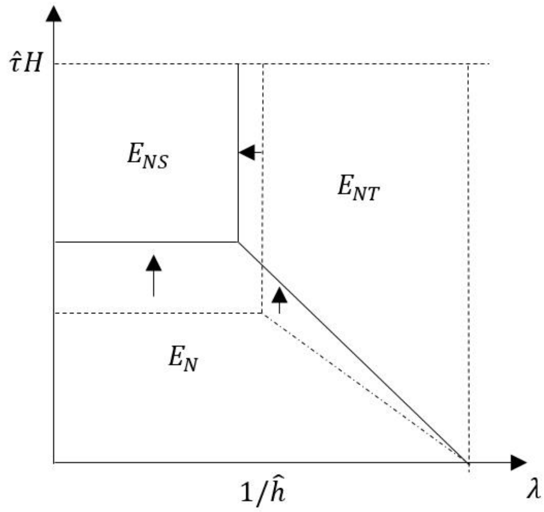

Figure 2.5: The Equilibrium if $h_N < \hat{h}(z_H, z_L)$ (when z_H increases)

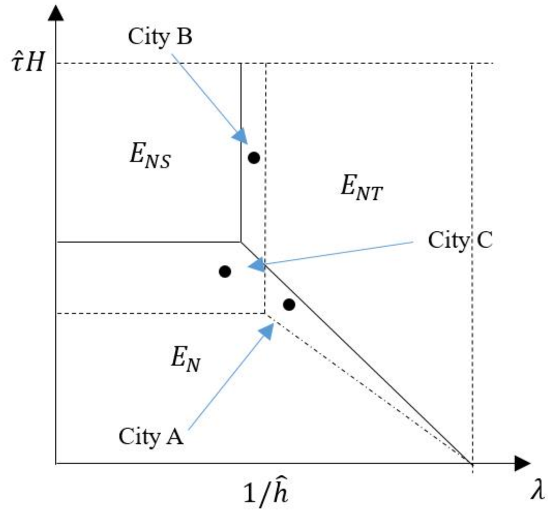

Figure 2.6: The diverse cities' configurations (when z_H increases)

Meanwhile, we also realize that the Proposition 2.5.1 doesn't tell us that higher z_H will always inhibit the emergence of TTs.

See Figure 2.6, for example in terms of the city A, in old equilibrium it accommodates NTs and TTs simultaneously, but in the new equilibrium after z_H increases for some factors outside our model, the city accommodates NTs only, in a sense the increase of z_H is *inhibiting* the emergence of TTs; in contrast, in terms of the city B, in old equilibrium it accommodates NTs and the self-employed simultaneously, but in the new equilibrium, the city accommodates NTs and TTs simultaneously, in a sense the increase of z_H is *encouraging* the emergence of TTs; finally, in terms of the city C, in old equilibrium it accommodates NTs and the self-employed, in the new equilibrium, the city accommodates NTs only, although TTs won't emerge in city C.

Hence, the story is quite different for the cities with advanced ICT infrastructures ($h_T < \hat{h}(z_H, z_L)$) and for those with less-advanced ICT infrastructures ($h_T > \hat{h}(z_H, z_L)$). For the cities that the city B represents, we have from equation (2-65), that

$$\frac{\partial \Delta c_H^{TS}}{\partial z_H} = \frac{1}{h_T(1-z_L)} - 1 > 0 \tag{2-91}$$

that is to say, a higher z_H will increase the attraction of TTs compared to being self-employed. In a word, the emergence of TTs is accompanied by a reduction of the self-employed skilled agents.

On the other hand, for the cities that the city A represents, we have from equation (2-61), that

$$\frac{\partial \Delta c_H^{NT}}{\partial z_H} = \frac{1}{h_N(1-z_L)}(1-\frac{h_N}{h_T}) - \hat{\tau}\frac{\partial H_N}{\partial z_H} \tag{2-92}$$

that is to say, a higher z_H will increase the attraction of NTs compared to TTs if $\hat{\tau}$ is low enough[5]. Thus, the managers will turn to organize NTs instead of TTs if the city is not that congested. The result is concluded in Corollary 2.5.1.

Corollary 2.5.1 *Suppose the policymaker in one city pursues one policy goal: increase H_T. We have for cities that the city A represents, the policymaker should decrease z_H to realize the goal; for the cities that the city B represents, the policymaker should increase z_H to realize the goal; for the cities that the city C represents, to increase or decrease z_H has no impact on H_T.*

We thus argue for one reason, that never has been explored in the existing literature, about why in reality the city/region which is fairly congested, meanwhile is equipped with fairly advanced ICT infrastructures, but experienced a quite low (even negative in specific period) growth rate of the body of teleworkers: the talent of the talented causes it!

Then, If we consider that the human capital is accumulating along the time, we can also derive the implication about the effect of the skill level of skilled agents on the evolvement of urban configuration through reorganization of teams.

We define z_H^1 and z_H^2 such that $\hat{h}(z_H^1) = h_N$ and $\hat{h}(z_H^2) = h_T$, respectively, then we have

$$z_H^1 = \frac{z_L}{1 - h_N(1-z_L)} \tag{2-93}$$

$$z_H^2 = \frac{z_L}{1 - h_T(1-z_L)} \tag{2-94}$$

Then it's easy to show that $z_H^2 > z_H^1$ as $h_T > h_N$ by assumption. We derive Figure 2.7 in which E_S emerges when z_H is between z_L and z_H^1, E_{NS} or E_N emerges if z_H is between z_H^1

[5] We show formally in the following $\partial H_N / \partial z_H$ is normally positive.

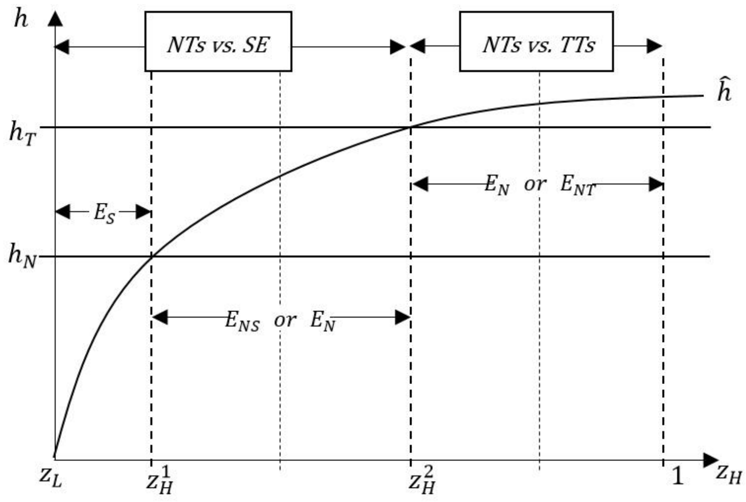

Figure 2.7: The impact of z_H on the equilibrium

and z_H^2, and E_N or E_{NT} emerges if z_H is between z_H^2 and 1. Then we calculate the threshold values z_H^3 and z_H^4 such that

$$\hat{\tau}H = (z_H^3 - z_L)[1 - \frac{h_N}{\hat{h}(z_H^3)}] \tag{2-95}$$

$$\hat{\tau}H = (z_H^4 - z_L)(1 - \frac{h_N}{h_T}) \tag{2-96}$$

then we have

$$z_H^3 = \frac{\hat{\tau}H + z_L}{1 - h_N(1 - z_L)} \tag{2-97}$$

$$z_H^4 = \frac{\hat{\tau}H}{1 - h_N/h_T} + z_L \tag{2-98}$$

we have also $z_H^3 < z_H^2$ if

$$\hat{\tau}H < [\frac{1 - h_N(1 - z_L)}{1 - h_T(1 - z_L)} - 1]z_L \tag{2-99}$$

and $z_H^4 > z_H^2$ if

$$\hat{\tau}H > [\frac{1 - h_N(1 - z_L)}{1 - h_T(1 - z_L)} - 1]z_L \tag{2-100}$$

and $z_H^4 < 1$ if

$$\hat{\tau}H < (1 - z_L)(1 - \frac{h_N}{h_T}) \tag{2-101}$$

which is just a should-have-been limit on parameters.

Hence we know that $z_H^3 < z_H^2$ and $z_H^4 > z_H^2$ won't hold simultaneously, either they are both smaller than z_H^2, or larger than z_H^2.

Therefore, we draw figures to illustrate the impact of the change of z_H on the urban

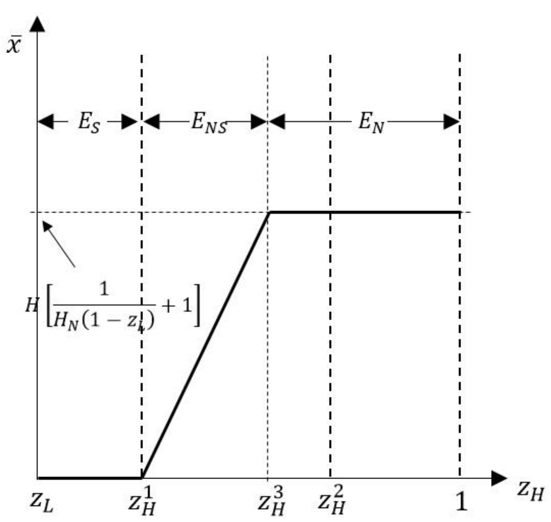

Figure 2.8: The impact of the change of z_H on the urban configuration (when $\hat{\tau}H < [\frac{1-h_N(1-z_L)}{1-h_T(1-z_L)} - 1]z_L$)

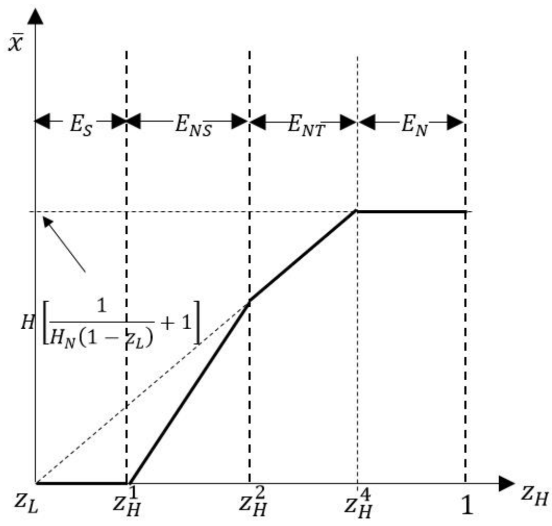

Figure 2.9: The impact of the change of z_H on the urban configuration (when $\hat{\tau}H > [\frac{1-h_N(1-z_L)}{1-h_T(1-z_L)} - 1]z_L$)

configuration through reorganization of teams: when the congestion effect is weak, TTs never emerges in equilibrium, along with the increase of z_H, the self-employed gradually turns to organize NTs, which enlarges the urban size before over the according trigger points (z_H^3); on the other hand, when the congestion effect is strong, similarly at the beginning the self-employed gradually turn to organize NTs but in slower pace, then TTs become favorable compared to being self-employed, the *residual* self-employed choose to organize TTs instead, there is a sudden *boom* in growth rate of TTs when z_H is just over z_H^2, then the managers in TTs gradually turn to organize NTs but in much slower pace, we could observe a *setback*, actually a negative growth rate in TTs thereafter until z_H^4, although the urban area will expand monotonically.

If we consider that the human capital is accumulating along the time in metropolitan area, this storyline fits the reality quite a well: the increase in human capital promotes the emergence of TTs at the first place, then turn to reverse it. As shown in Figure 2.12, TTs only show up in the middle range of z_H, its proliferation rate goes up, then goes down (see Figure 2.10).

Proposition 2.5.2 *When the congestion effect is strong enough, that is when $\hat{\tau}H > [\frac{1-h_N(1-z_L)}{1-h_T(1-z_L)} - 1]z_L$), along with the increase of z_H, there is an singular point over which a sudden boom is experienced in the growth rate of TTs, then we witness a setback, actually a negative growth rate of TTs thereafter, it exhibits an inversed U-shape pattern.*

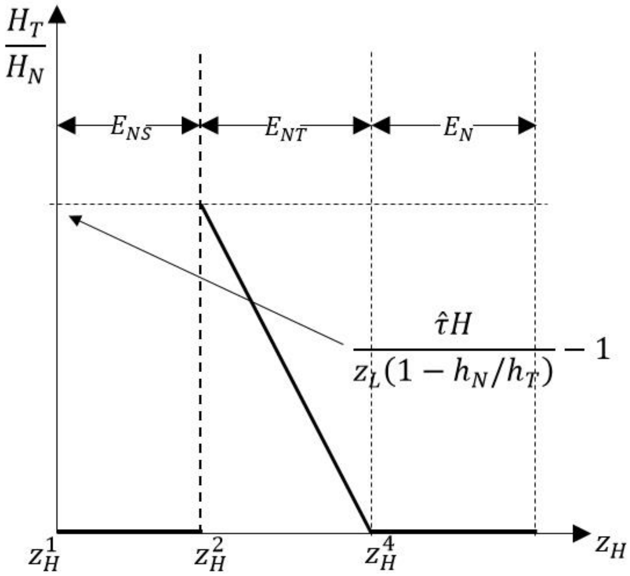

Figure 2.10: The impact of the change of z_H on the ratio of TTs to NTs (when $\hat{\tau}H > [\frac{1-h_n(1-z_L)}{1-h_t(1-z_L)}-1]z_L$)

2.5.2 Effects of Population Growth

In this subsection, we derive implications about the impact on the proportion of NTs and TTs from a proportional growth in urban population.

In E_{NS}, we have

$$H_N^{NS} = \frac{(z_H - z_L)[1 - h_N/\hat{h}(z_H, z_L)]}{\hat{\tau}(\tau_H, \tau_L)h_N(1 - z_L)} \tag{2-102}$$

$$L_N^{NS} = \frac{(z_H - z_L)[1 - h_N/\hat{h}(z_H, z_L)]}{\hat{\tau}(\tau_H, \tau_L)h_N^2(1 - z_L)^2} \tag{2-103}$$

$$H_S^{NS} = H - \frac{(z_H - z_L)[1 - h_N/\hat{h}(z_H, z_L)]}{\hat{\tau}(\tau_H, \tau_L)h_N(1 - z_L)} \tag{2-104}$$

$$L_S^{NS} = L - \frac{(z_H - z_L)[1 - h_N/\hat{h}(z_H, z_L)]}{\hat{\tau}(\tau_H, \tau_L)h_N^2(1 - z_L)^2} \tag{2-105}$$

In E_N, we have

$$H_N = H \tag{2-106}$$

$$L_N = \frac{H}{h_N(1 - z_L)} \tag{2-107}$$

$$L_S^N = L - \frac{H}{h_N(1 - z_L)} \tag{2-108}$$

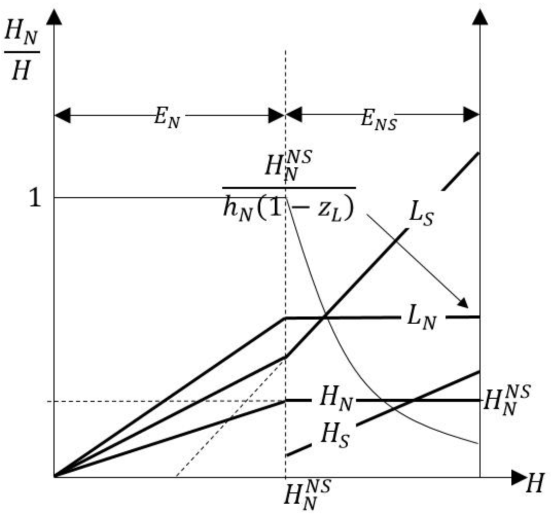

Figure 2.11: The impact of the change of H (when $h_N < \hat{h} \leq h_T$)

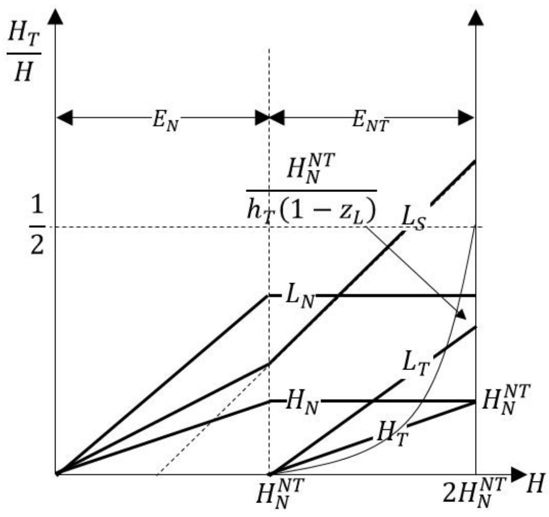

Figure 2.12: The impact of the change of H (when $h_N < h_T < \hat{h}$)

In E_{NT}, we have

$$H_N^{NT} = \frac{(z_H - z_L)[1 - h_N/h_T]}{\hat{\tau}(\tau_H, \tau_L)h_N(1 - z_L)} \tag{2-109}$$

$$L_N^{NT} = \frac{(z_H - z_L)[1 - h_N/h_T]}{\hat{\tau}(\tau_H, \tau_L)h_N^2(1 - z_L)^2} \tag{2-110}$$

$$H_T^{NT} = H - \frac{(z_H - z_L)[1 - h_N/h_T]}{\hat{\tau}(\tau_H, \tau_L)h_N(1 - z_L)} \tag{2-111}$$

$$L_T^{NT} = \frac{H}{h_T(1 - z_L)} - \frac{(z_H - z_L)[1 - h_N/h_T]}{\hat{\tau}(\tau_H, \tau_L)h_N h_T(1 - z_L)^2} \tag{2-112}$$

$$L_S^{NT} = L - \frac{H}{h_T(1 - z_L)}] - \frac{(z_H - z_L)[1 - h_N/h_T]}{\hat{\tau}(\tau_H, \tau_L)h_N(1 - z_L)}[\frac{1}{h_N(1 - z_L)} - \frac{1}{h_T(1 - z_L)}] \tag{2-113}$$

If $h_N < \hat{h} \leq h_T$, along with the proportional growth in population, the equilibrium turns from E_N to E_{NS} (see Figure 2.11). The reason behind this transition is simple: the congestion effect in more congested city is larger, and thus the managers in NTs realize that it's more profitable to work on their own, and live at suburban area to avoid the relatively high urban cost.

If $h_N < h_T < \hat{h}$, along with the proportional growth in population, the equilibrium turns from E_N to E_{NT} (see Figure 2.12). The reason behind this transition is similar with the above: the congestion effect in more congested city is larger, the managers try to avoid the high urban cost, and when organizing TTs turns out to be more profitable than working on their own as a method to get over the urban cost, TTs emerge and increase rapidly. The results are concluded in the Proposition 2.5.3.

Proposition 2.5.3 *When organizing TTs becomes feasible, along with a proportional growth in urban population, the growth rate in proportion of TTs will be slower than it at the beginning, then accelerate and exceed it then.*

2.6 Concluding Remarks

Although teleworking is believed to reduce office rental costs, alleviate commuting congestion, there still are many firms, especially large IT firms whose tasks are considered as easily telework-able, saying "NO" to teleworking program: either repeal it recently (e.g. Yahoo, IBM), or never initiate it (e.g. Google, Apple). The existing studies give little clue to explain this trend.

We construct a model in this chapter to explore the reason behind it. We found firms led by more skillful skilled agents prefer conventional/normal team than teleworking team, because the inferior communication technology within teleworking teams (compared to F2F communication within conventional/normal team) undermines the "leverage" of entrepreneur/manager's skill on the profit.

Chapter 3

Multinationals and Roles of the Middle Managers on Teleworking

3.1 Introduction

The recent development of ICTs globally induces a boom in volume of cross-border service offshoring[1], especially in sector of the Knowledge Intensive Business Services (KIBS), meanwhile as we introduced in the chapter 2, teleworking as a feasible working arrangement that reaps the benefits released from the development of ICT locally has been also attracting tremendous attentions in public.

What's the relation between service offshoring and teleworking as two similar but different ICT-driven phenomena? In this chapter, we try to explore this issue.

3.1.1 Multinationals and Teleworking in Developing Countries

Teleworking gains particular importance in developing economies, such as India, China, Brazil, where some issues which are common among those countries at similar stage of development include congested traffic patterns from rapid urbanization, increased use of electronic communication and increased dual earner families in the workforce.

Multinational corporations can provide developing countries (host countries) with many benefits, e.g. technology transfer[2], improving the balance of payments. Have teleworking

[1]Offshoring refers to agents in different countries being able to collaborate in teams.

[2]Multinationals might bring with them technology and production methods that are probably new to the host country, workers in host country will be trained to use the new technology meanwhile domestic firms might see the benefits of the new technology.

gained popularity in the USA (BLS, 2019; Owl Labs and Global Workplace Analytics, 2019) and in Europe, do experienced multinationals also "introduce" teleworking into host countries in reality? Is it good for the host country?

Ndubisi and Kahraman (2005) compared teleworking adoption decision processes of multinational firms operating in Malaysia and Malaysian indigenous firms. A total of 98 organizations offered usable responses for this study out of a total of 162 Malaysian organizations. The authors found that "in both multinational and Malaysian firms, the nature of work, organizational design, transportation problems, and relative advantage are important telework(ing) drivers".

Anell and Hartmann (2007) provides several very good examples of flexible work arrangement (FWA) (teleworking is the most common type of FWA) in Asia offered by multinationals. For example, from all of the FWAs that Hewlett Packard (HP) offers, the most successful is the work-at-home option in China. Subject to business needs, 50% of employees in China up to 5,000 employees, who are predominately local and some are expatriates (less than 10%), can spend 1-2 days a week working from home. The policy contributes to financial savings for the company (employees are required to share sitting areas with peers, no need for office expansion and cost is therefore reduced) and female professionals experience less stress from trying to balance work-life. The other multinationals who offered FWAs in Asia include Cadbury Schweppes, Dow Chemical Company, Kraft Foods, Merck and Co., Royal Dutch Shell and State Street Corporation, some of them are subject to specific area, such as Royal Dutch Shell in Singapore, and some are subject to multiple area, such as Dow Chemical Company in Hong Kong, Japan and Taiwan.

Bernardino, et al (2012) developed guidelines for the implementation and management of teleworking based on one Brazilian subsidiary of a multinational organization that provides IT services[3], where the number of employees is about 14,000 with 2,500 manager, among them the authors "interview 12 teleworkers working with IT, 6 teleworkers' managers, and 1 HR manager[4]" to derive the data.

Raghuram (2014) identified the potential and problems that the relatively new work mode - teleworking- can offer to employees in India. The author found that "the first movers in

[3]As the authors introduce, in Brazil the growth rate of IT sector exceeds the world's average, and one of the biggest challenges for the Brazilian IT sector is the shortage of skilled professionals, teleworking has been implemented by organizations to be competitive in the war for talent.

[4]The primary criteria used to choose the subjects to be interviewed, teleworkers are those who have to be working as teleworkers for a minimum of six months, teleworkers' managers are those who manage a minimum of two teleworkers, and HR managers are those who have participated in the process of implementing teleworking in the Brazilian subsidiary of the organization.

transplanting teleworking in India were multinationals (such as IBM and American Express) who expected beneficial outcomes similar to those experienced in the West", and "in response to industry pressures introduced by the multinationals, home-grown Indian organizations are also offering teleworking".

Raghuram and Fang (2014) explored how perception of supervisory power (of employees) determines the use of teleworking in a study carried out in China. Teleworking in China is regarded as one of practice introduced by multinationals, and an example of spillover effects of increased exposure to Western approaches to human resource management (HRM) through tremendous inward foreign direct investments (FDI) in recent decades[5]. Based on survey data collected from teleworkers working in four multinational consulting firms[6] in Beijing, China, where all the firms were private consulting firms who had teleworking policies worldwide, the authors argued that teleworking intensity[7] will be greater when subordinates perceive that their supervisors' power are intact and that the socially approved relationships are not diminished.

Soenanto, et al (2016) concluded that the multinational companies under surveyed should give further attention to the importance of teleworking system to increase the productivity of employees in Jakarta, Indonesia.

We conclude the findings of activities of multinationals in developing countries (host countries) in existing literature in the following lines: (1) firstly, although teleworking is still marginal in developing countries, multinationals are the first adopters of it, as they have done in the past in the process of introducing other Western approaches in various fields (Raghuram and Fang, 2014); (2) financial savings in office rental costs and comparative advantage in competition for talents are the primary reasons (meanwhile referred benefits) of adopting teleworking (Anell and Hartmann, 2007); (3) Spillover effect to home-grown, indigenous companies in host countries is expected (Raghuram, 2014).

[5] In our model we introduced blow, we won't make the strong assumption where teleworking itself is one kind of technology transfer through inward FDI by multinationals, but instead we assume that the communication friction will be lower within local teams who subordinate to multinationals compared to those local teams who don't subordinate to any multinational organization. Thus whether local teams in host country is organized in traditional form, or in remote form will be determined endogenously.

[6] As the authors clarified that this sample selection bias is because teleworking is still a new work arrangement in China and the first adopters are consulting and sales organizations.

[7] Teleworking intensity refers to the number of days in a week that the person teleworks (Gajendran and Harrison, 2007).

3.1.2 Extension and Primary Results

We build a model to explore how the decision of to be multinational and the decision to adopt teleworking program in host country are intertwined to each other. Not all multinationals will automatically adopt teleworking in host country in our model, it depends on contextual parameters.

Specifically, we try to uncover the role of the skill level of local elites in host country in determining the proportion of teleworking teams locally on one side, and/or the offshoring patterns globally on the other side. Our model also exclusively illustrates how the decision to offshore may be associated with transformations in organizational structure of the firms, who may introduce intermediate layers of middle managers, and/or introduce teleworking program.

As the results, (1) firstly, we recognize that the "thick shield effect" and the "(composite) wage premium effect" will together determine the multinationals' decision in either traditional team or teleworking teams to be organized; (2) secondly, we identify a non-linear relation between the skill level of local elites in the host country and the proportion of teleworking teams, which is regarded as a proxy of the proliferation rate of teleworking teams, in general along with the human capital accumulation of local elites, it exhibits in sequence neutral, positive, negative then positive effect on the proliferation rate of teleworking teams with appropriate parameters; (3) thirdly, we also derive in total six equilibrium offshoring patterns (including whether teleworking teams are adopted or not in host country).

Our model extends the model in the chapter 2 in a sense that (1) firstly, the model in the chapter 2 includes only two kinds of labor: the skilled and the unskilled labor, here we add a new type of labor, thus we include high-skilled, middle-skilled and low-skilled labor, this extension allows us to focus on the role of middle-skilled labor in determining multinationals' policy on teleworking; (2) secondly, the model in the chapter 2 includes only one region/area, here we extend it to include two regions/countries, such that this extended framework accommodates to deal with offshoring emerging globally, and teleworking emerging locally simultaneously; (3) thirdly, in the chapter 2 entrepreneurs are only allowed to organize two-layer teams, here the entrepreneurs are allowed to organize either two-layer or three-layer teams. With respect to the other important aspects that we differ from the existing literature, it's similar to the aspects where the model in the chapter 2 differs from the existing literature.

The remainder of the paper contains six sections. Section 3.2 introduces the general setups in Antras-Rossi-Hansberg-Garicano framework, especially how the production is three-layer knowledge hierarchical teams is carried out is introduced. Section 3.3 introduces our own model. Section 3.4 gives the equilibrium conditions, the algorithm, we solve it analytically. Section 3.5 derives propositions through comparative statics. Section 3.6 makes the concluding remarks.

3.2 Framework: General Setups

3.2.1 Production in Three-layer Knowledge Hierarchical Teams

In this subsection, we introduce the general setup that is common in models that build on the ARG framework. Specifically, we illustrate how production in a three-layer[8] hierarchical teams is carried out, and how the earnings of entrepreneur is derived. Meanwhile, we will compare to the earnings of entrepreneur in two-layer team, and highlight the trade-off between two-layer and three-layer teams.

Agents are endowed with 1 unit of time and a skill level z, the time is either used to draw problems from the problem pool, or consumed to communicate with the subordinates to solve the problem. As in Antras, Garicano and Rossi-Hansberg (2006a), we normalize the set of problems so that the skill level z becomes also the proportion of problems an agent can solve, it's equivalent to assume that the distribution of (the complexity of) problems is uniform over $[0, 1]$.

Suppose a three-layer team is composed of one entrepreneur with skill level z_2, n_1 middle managers with skill level z_1 and n_0 production workers with skill level z_0. The workers each spend 1 unit of time to draw a unit measure of problems, solve a fraction z_0 of problems and pass on the residual $(1 - z_0)$ to the middle managers' layer, then the middle managers solve a fraction $(z_1 - z_0)$ of problems and pass on the residual $(1 - z_1)$ to the entrepreneur's layer, finally the entrepreneur solves a fraction $(z_2 - z_1)$ of problems. Hence, in total the hierarchical team as a whole solve $n_0 z_2$ problems.

We use y to denote the output of team, which is measured by how many problems are solved by the team as a whole, then we have

$$y = n_0 z_2 \tag{3-1}$$

where as we treat the "solved" problem as the numeraire, thus y represents the revenue of the team as well.

[8] In the chapter 2, we illustrate how production is carried out in a two-layer hierarchical teams.

Production is accomplished whenever either workers, middle managers or the entrepreneur solve the problems, so y can be decomposed into three portions:

$$y = \underbrace{n_0 z_0}_{Solved\ in\ Workers'\ Layer} + \underbrace{n_0(z_1 - z_0)}_{Solved\ in\ Middle\ Managers'\ Layer} + \underbrace{n_0(z_2 - z_1)}_{Solved\ in\ Entrepreneur's\ Layer} = n_0 z_2 \tag{3-2}$$

where the middle managers' layer functions like a "shield", in a sense only $n_0(1-z_1)$ problems will be passed on to the entrepreneur's layer[9].

On the other hand, since each entrepreneur is endowed with 1 unit of time, we have the time constraint of the entrepreneur as given by

$$n_0 h_1(1 - z_1) \leq 1 \tag{3-3}$$

where the LHS of equation (3-3) represents the time demand of entrepreneur, each problem will consume h_1 units of time to be communicated to the entrepreneur, thus in total it will take $n_0 h_1(1 - z_1)$ units of time. The equation (3-3) says that the demand can not exceed the time supply, which equals 1, of the entrepreneur.

Meanwhile, since each middle manager is endowed with 1 unit of time as well, we have time constraint of the middle managers as given by

$$n_0 h_0(1 - z_0) \leq n_1 \tag{3-4}$$

where similarly the LHS of equation (3-4) represents the time demand of middle managers, each problem will consume h_0 units of time to be communicated to the middle managers, thus in total it will take $n_0 h_0(1-z_0)$ units of time. Meanwhile the RHS of equation (3-4) represents the time supply of the middle managers in total. The equation (3-4) says that the demand can not exceed the total time supply of the middle managers.

Denote the wage rate of production workers and middle managers by w_0 and w_1, respectively. The entrepreneur is assumed to absorb all the operating profits of the firms, thus the earnings of the entrepreneur is given by

$$w_2 = y - n_1 w_1 - n_0 w_0 = n_0(z_2 - w_0) - n_1 w_1 \tag{3-5}$$

[9]In two-layer team, $n_0(1 - z_0)$ problems will be passed on to the entrepreneur's layer, which is larger than $n_0(1 - z_1)$ as $z_1 > z_0$ be settings.

From equation (3-5), in order to maximize her earnings, the entrepreneur should enlarge the team size of production workers n_0, and shrink the team size of middle managers n_1 as far as possible. With equation (3-3), the entrepreneur thus will use up her time endowment to make n_0 as large as possible, meanwhile with equation (3-4) the time endowment of middle managers will be all used up to serve to answer workers' unsolved problems. In a word, the time constraints must be bonding. Hence, we have

$$n_0 = \frac{1}{h_1(1 - z_1)} \tag{3-6}$$

$$n_1 = \frac{h_0(1 - z_0)}{h_1(1 - z_1)} \tag{3-7}$$

and the ratio of team size of middle managers to production workers is given by

$$\frac{n_1}{n_0} = h_0(1 - z_0) \tag{3-8}$$

Substitute n_0 and n_1 back into equation (3-5), we have

$$w_2 = \frac{z_2 - w_0 - h_0(1 - z_0)w_1}{h_1(1 - z_1)} \tag{3-9}$$

3.2.2 Trade-offs Between Two-layer and Three-layer Teams

Remind that in two-layer team, given the wage rate of the production workers by w_0, the earnings of the entrepreneur is given by

$$w_2' = n_0'(z_2 - w_0) = \frac{z_2 - w_0}{h_1(1 - z_0)} \tag{3-10}$$

where we presume that the communication technology in two-layer team is same as the communication technology between the middle and top layer in three-layer team.

Thus we have the differential of the earnings of entrepreneur between through organizing three-layer and two-layer team as denoted by $\Delta w_2 \equiv w_2 - w_2'$

$$\Delta w_2 = \underbrace{\frac{z_2 - w_0}{h_0(1 - z_0)(1 - z_1)}(z_1 - z_0)}_{\textit{The Merit of the Shield}} - \underbrace{\frac{h_0(1 - z_0)}{h_1(1 - z_1)}w_1}_{\textit{The Demerit of the Shield}} \tag{3-11}$$

With equation (3-11), from the perspective of the entrepreneur, the pros and cons of adding a new layer is very straightforward: the new layer shields the entrepreneur form more routine problem, which helps her enlarge the size of production team and for more knowledgeable entrepreneur, the merit will be larger; on the other hand, the entrepreneur must pay for the cost of the shield, namely the wage rate of the middle managers.

One interesting point is to look at the role of local communication efficiency: h_0. Higher h_0 will decrease the merit but increase the demerit of adding a new layer.

3.3 Model

In this section, we build our own model, in which firms are organized in either two-layer or three-layer knowledge hierarchical structure. Three types of agents are introduced: the high-skilled agents with skill level z_H, the middle-skilled agents with skill level z_M and the low-skilled agents with skill level z_L, where we assume throughout $z_H > z_M > z_L$.

We introduce the basic settings firstly, then uncover the behaviors of the high-skilled agents in the North, the middle-skilled and the low-skilled agents in the South in order, thirdly we give several conditions that must be satisfied in equilibrium, fourthly we solve it analytically and derive propositions through the comparative statics.

3.3.1 Basic Settings

Suppose that the world economy consists of two countries: the North and the South, and is inhibited by 1 unit of population with H units of high-skilled agents, M units of middle-skilled agents and L units of low-skilled agents, where $H + M + L = 1$.

We further assume that the North and the South are endowed with distribution of skills asymmetrically, with the North endowed with agents with higher skills. We capture this feature in a stark way: all high-skilled agents live at the North, meanwhile all middle-skilled and low-skilled agents live at the South.

Suppose that the agents in the South live at a linear space $[0, +\infty)$, where a prior Central Business District (CBD) is located at the origin. At each location, 1 unit of land is supplied inelastically and all lands are assumed to be owned by the absentee landowners. Each unit of land is heterogenous solely with respect to the distance to the CBD. In contrast, for simplicity, we won't consider the spatial problem in the North.

Sorting, Matching and Organizational Patterns. Let's start from the analysis of the sorting and matching problem of the high-skilled agents. Potentially, the high-skilled agents

Table 3.1: Sorting, Matching and Organizational Patterns

	2L	3LN[1]	3LT
Low-skilled(S[2])	W[3]	W	W
Middle-skilled(S)	W,E	M	M
High-skilled(N)	E	E	E

[1] 3LN represents the three-layer team with low and middle-skilled agents organized in normal way, and 3LT represents the three-layer team with low and middle-skilled agents organized in remote way.
[2] S represents the South, and N represents the North.
[3] W represents the production worker, M represents the middle manager and E represents the entrepreneur.

are allowed to become entrepreneur, middle manager or production worker. However, we prove in the following that the high-skilled agents will never become middle manager or production worker, the result is concluded in the Lemma 3.3.1, and the proof is given in the Appendix.

Lemma 3.3.1 *The high-skilled agents are never motivated to be middle manager or production worker in teams.*

Hence, the high-skilled agents will either choose to become entrepreneur, or choose to work on their own to become self-employed.

Then, we turn to the analysis of the matching and sorting problem of the low-skilled agents. Potential, similarly the low-skilled agents are allowed to play either role in teams. However, we prove in the following that the low-skilled agents will never become entrepreneur or middle manager, the result is concluded in the Lemma 3.3.2, and the proof is given in the Appendix.

Lemma 3.3.2 *The low-skilled agents are never motivated to be entrepreneur or middle manager in teams.*

Hence, the low-skilled agents will either choose to become production worker, or choose to work on their own to become self-employed.

In contrast to the limited roles of the high-skilled and low-skilled agents in teams, the middle-skilled agents are probable to play either role: production worker, middle manager, entrepreneur or self-employed.

Then, we turn to the introduction of the feasible organizational patterns. Firstly, either two-layer or three-layer teams are allowed to be organized by entrepreneurs. Secondly, with respect to three-layer teams, the local workforce can be organized in normal teams, or in teleworking teams.

We summarize the sorting, matching and organizational patterns in the following (see Table 3.1).

Communication Costs and Technology Transfer Patterns. In this subsection, we introduce communication (time) costs per problem in various specified contexts. We have in total five different contexts in which the communication occurs between the agent in lower layer and the agent in upper layer (see Table 3.2).

Then, we make several assumptions in terms of their relationships. Specifically, these assumptions mainly based on two more fundamental ideas:

First is the factor about the "physical distance". Based on the "Media Richness Theory (MRT)" introduced by Richard Daft and Robert Lengel in 1986, the richer communication media (e.g. face-to-face communication, etc.) are generally more effective for communicating equivocal issues in contrast with leaner, less rich media (e.g. E-mail, telephone, etc.)[10].

Second is the factor about the "social distance". The existence of the "social distance" implies that cross-cultural communication will be normally more difficult, and thus less efficient than communication between agents with the similar demographical features. An obvious example is about the language, where the people who use different language will increase the probability of misunderstanding, and undermine the efficiency of communication.

Therefore, based on the fundamental ideas above, we conclude in a sense that (1) the communication with *rich* media will be more efficient, less time-consuming than the communication with *poor* media; (2) the communication within country will be more efficient, less time-consuming than the communication across border.

Specifically, in the Assumption blow we firstly assume that h_I is the highest among others, then h_T the second highest, finally h_N the lowest in order. Firstly, $h_I > h_T$ is because although the both involves the communication through the use of telecommunication devices, but the cross-border communication involves *more* cross-cultural interactions, the "social distance" between the involved agents is normally much *longer* than those who're with the same nationality. Secondly, $h_T > h_N$ is because compared to face-to-face communication realized by commuting together to the office, the telecommunication is innately accompanied by more noises.

Assumption 3.3.1 $h_I > h_T > h_N$

Furthermore, in the Assumption blow we then assume that if the southern team is affiliated to the northern entrepreneur, both face-to-face communication efficiency and telecommunication efficiency are somehow weakly improved[11].

[10] The richness is defined by Daft and Lengel as "the ability of information to change understanding within a time interval" (Daft and Lengel, 1986).

[11] In Antras, Garicano and Rossi-hansberg (2007b), they describe it as a type of technology transfer.

Table 3.2: Classification of Contexts and Communication Costs

	Time Cost	Cross-border/Domestic[1]	NT/TT[2]	Independent/Hierarchical[3]
Type 1	h_N	Domestic	NT	Independent
Type 2	h_T	Domestic	TT	Independent
Type 3	$\gamma_N h_N$	Domestic	NT	Hierarchical
Type 4	$\gamma_T h_T$	Domestic	TT	Hierarchical
Type 5	h_I	Cross-border	NG	Both

[1] Cross-border refers to the context in which communication occurs between agent in the South and agent in the North, and Domestic refers to the context in which communication occurs within the South.

[2] NT refers to the normal team in which communication occurs face-to-face (F2F), and TT refers to the teleworking team in which communication occurs through telephone, E-mail and other telecommunication devices.

[3] Independent refers to the context in which the agents involved in communication don't belong to any larger hierarchical structure, and Hierarchical refers to the context in which the agents involved in communication do belong to a larger hierarchical structure.

Table 3.3: Technology Transfer Patterns

	F2F (γ_N)	Telecommunication (γ_T)
Neutual (Symmetic)	$\gamma_N = 1$	$\gamma_T = 1$
F2F-augmenting (Asymmetric)	$\gamma_N/\gamma_T < 1$	$\gamma_T \leq 1$
Telecommunication-augmenting (Asymmetric)	$\gamma_N \leq 1$	$\gamma_T/\gamma_N < 1$

Assumption 3.3.2 $0 < \gamma_N \leq 1$, *and* $0 < \gamma_T \leq 1$

Besides, we also distinguish several technology transfer patterns: firstly, if $\gamma_N = \gamma_T$, we say that the technology transfer pattern is symmetric, and if $\gamma_N \neq \gamma_T$, in contrast we say that the technology transfer pattern is asymmetric; secondly, we further identify two types of asymmetric technology transfer patterns in the following, if $\gamma_N < \gamma_T$, we say that the technology transfer pattern is F2F-augmenting, if $\gamma_N > \gamma_T$, we say that the technology transfer pattern is telecommunication-augmenting (see Table 3.3).

Basically, the North brings to the South two things: (1) agents with superior skill level z_H; (2) access to a weakly better technology for local communication.

3.3.2 Behavior of the High-skilled Agents

As we show above, the high-skilled agents are never motivated to be middle manager or production worker in teams, thus the choice is between to be entrepreneurs, or to maintain self-employed, and if the high-skilled agents decide to be entrepreneurs, then choose which type of teams, 2L with either middle-skilled or low-skilled agents, or 3LN or 3LT, to organize.

Strategic Interactions. By our settings, the strategies of other high-skilled agents other than, say agent $i \in \{1, 2, \ldots, H\}$, play a non-trivial role on agent i's strategy.

Let (A^H, u) be a game with H agents where A^H is the set of strategy profile. The strategy set is symmetric in a sense that all high-skilled agents own the same strategy set A, where $A \equiv \{X, Y, N, T, S\}$.

Specifically, X represents the strategy of organizing two-layer team with low-skilled agents, Y represents the strategy of organizing two-layer team with middle-skilled agents, N represents the strategy of organizing three-layer team with middle-skilled and low-skilled agents further organized in normal way, T represents the strategy of organizing three-layer team with middle-skilled and low-skilled agents further organized in teleworking way, S represents the strategy of maintaining self-employed.

Suppose any specific strategy profile $a = (a_1, a_2, \ldots, a_H) \in A^H$, the payoff profile $u(a) = (u_1(a), u_2(a), \ldots, u_H(a))$ is derived from being evaluated at a. Furthermore, let a_i be the strategy for agent i and a_{-i} be the strategy profile (a vector of strategies) for all agents other than i, thus $a = (a_i, a_{-i})$ for $i \in \{1, 2, \ldots, H\}$.

Payoff Functions. Let w_H^X, w_H^Y, w_H^N, w_H^T and w_H^S be the income when the high-skilled agents decide to organize two-layer team with low-skilled, middle-skilled agents, organize three-layer team with low skilled and middle-skilled agents who are further organized in normal way and teleworking way, and maintain self-employed, respectively.

$$w_H^X(a) = \frac{z_H - w_L^X(a)}{h_I(1 - z_L)} \tag{3-12}$$

$$w_H^Y(a) = \frac{z_H - w_M^Y(a)}{h_I(1 - z_L)} \tag{3-13}$$

$$w_H^N(a) = \frac{z_H - w_L^N(a) - \gamma_N h_N (1 - z_L) w_M^N(a)}{h_I(1 - z_M)} \tag{3-14}$$

$$w_H^T(a) = \frac{z_H - w_L^T(a) - \gamma_T h_T (1 - z_L) w_M^T(a)}{h_I(1 - z_M)} \tag{3-15}$$

and

$$w_H^S = z_H \tag{3-16}$$

where $w_L^X(a)$, $w_M^Y(a)$, $w_L^N(a)$ and $w_L^T(a)$ represent the wage expenditure per production worker[12], $w_M^N(a)$ and $w_M^T(a)$ represent the wage expenditure per middle manager, respectively.

One noticeable feature in our model, as we will introduce in detail in the following, is that the labor cost differential between office worker and teleworker, which is one of important factor that affects the decision in organizational form of entrepreneur, is affected at the same time by the pattern of the decisions in organizational form of all entrepreneurs.

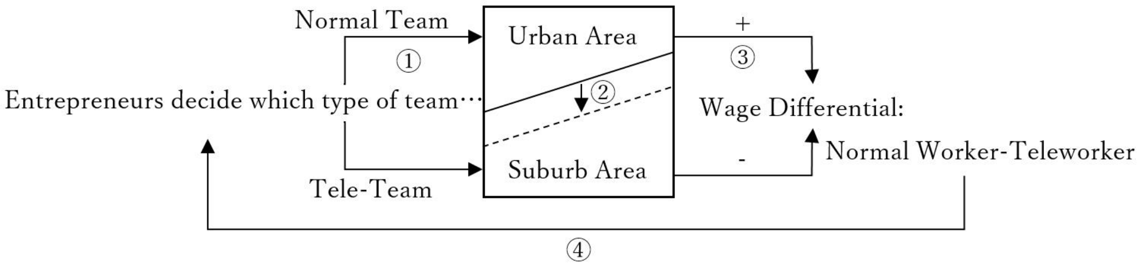

Figure 3.1: Mechanism of Strategic Interactions among High-skilled Agents

Let's take an example to see how this mechanism works: say if more entrepreneurs decide to turn to organize normal teams in the South (through ①); then as the agents in normal teams are obliged to commute, they will value more (compared to the agents in tele-teams) the opportunity to live closed to the CBD and thus are willing to pay more, they will end up with living at urban area; and ① leads to fiercer competition in urban land, which further leads to (a) urban rents lift up; (b) urban area expands (through ②); ② results in a higher extra compensation burdened by entrepreneurs to hire normal workers rather than teleworkers (through ③); ③ thus discourages entrepreneurs to organize normal teams (through ④).

3.3.3 Behavior of the Middle-skilled Agents

The middle-skilled agents are probable to play either role: production worker, middle manager, entrepreneur or self-employed. Specifically, the middle-skilled agents own six options: become middle manager in three-layer team working at office or home, become entrepreneur in two-layer team working at office or home, become production worker in two-layer team led by high-skilled agents, or maintain self-employed. They will earn $w_M^N(a)$, $w_M^T(a)$, $w_M^{Z_1}(a)$, $w_M^{Z_2}(a)$,

[12]Notice $w_M^Y(a)$'s subscript is M but not L, as in this case the middle-skilled agents, rather than the low-skilled agents, play the role of production workers.

$w_M^Y(a)$ and $w_M^S = z_M$ in respective case, where

$$w_M^{Z_1}(a) = \frac{z_M - w_L^{Z_1}(a)}{h_N(1 - z_L)} \tag{3-17}$$

$$w_M^{Z_2}(a) = \frac{z_M - w_L^{Z_2}(a)}{h_T(1 - z_L)} \tag{3-18}$$

Strategic Interactions. Notice that the strategic interactions are not limited among high-skilled agents, it may occur within the group of middle-skilled agents, and between these two groups. Let's take an example to see how this mechanism works: the mechanism of ① to ③ is just the same as in Figure 3.1, ④ implies that higher extra compensation encourages middle-skilled agents to organize Z_2 (through ⑤), less competition in urban land declines urban rents in average and shrinks urban area (through ⑥), which results in a less extra compensation to hire normal workers rather than teleworkers (through ⑦), finally it encourage high-skilled agents to organize N (through ⑧).

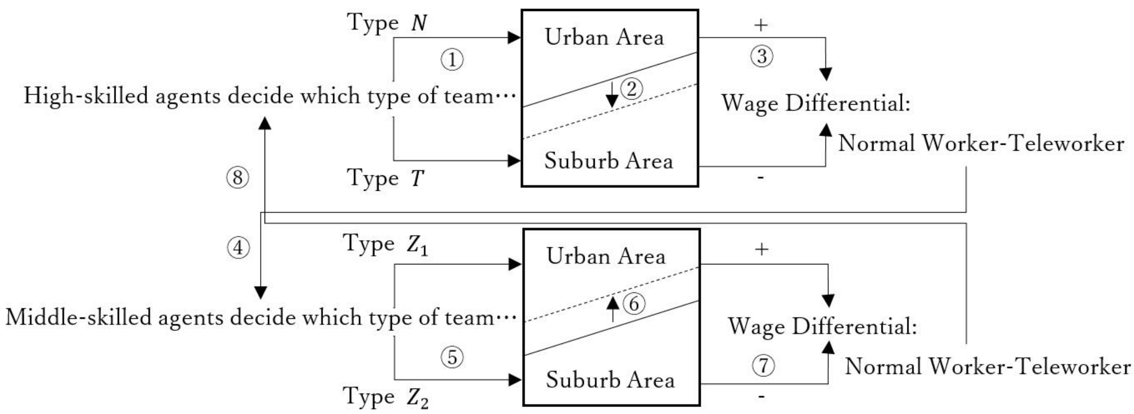

Figure 3.2: Mechanism of Strategic Interactions between Middle-skilled and High-skilled Agents

Therefore, formally the game we specified above is modified to include middle-skilled agents: let $(A^H \times B^M, u)$ be a game with $H + M$ agents where $A^H \times B^M$ is the set of strategy profile. The strategy set is quasi-symmetric in a sense that all high-skilled agents own the same strategy set A, where $A = \{X, Y, N, T, S\}$, meanwhile all middle-skilled agents own the same strategy set B, where $B = \{Z_1, Z_2\}$.

Suppose any specific strategy profile $(a, b) = (a_1, a_2, \ldots, a_H, b_1, b_2, \ldots, b_M) \in A^H \times B^M$, the payoff profile $u(a, b) = (u_1(a, b), u_2(a, b), \ldots, u_H(a, b))$ is derived from being evaluated at (a, b). Furthermore, let a_i be the strategy for high-skilled agent i and a_{-i} be the strategy

Table 3.4: Types of Teams

Symbol	# of Layers	Bottom	Medium	Top	Inter/Intra-national	Normal/Remote
X	2	Low	NG	High	Inter	NG
Y	2	Middle	NG	High	Inter	NG
Z_1	2	Low	NG	Middle	Intra	Normal
Z_2	2	Low	NG	Middle	Intra	Remote
N	3	Low	Middle	High	Inter	Normal
T	3	Low	Middle	High	Inter	Remote

profile (a vector of strategies) for all high-skilled agents other than i, and let b_j be the strategy for middle-skilled agent j and b_{-j} be the strategy profile for all middle-skilled agents other than j, thus $(a, b) = (a_i, a_{-i}, b) = (a, b_j, b_{-j})$ for $i \in \{1, 2, \ldots, H\}$, $j \in \{1, 2, \ldots, M\}$.

In conclusion we have six types of teams (see Table 3.4), within which four of them are cross-border (international) teams and led by high-skilled agents, the residual two of them are domestic (international) teams and led by middle-skilled agents.

Utility Functions. Presume the land rent function as $r(x; a)$, where x denotes the distance to the CBD, let $c_M^N(x; a)$, $c_M^T(x; a)$, $c_M^{Z_1}(x; a)$, $c_M^{Z_2}(x; a)$, $c_M^Y(x; a)$ and c_M^S be the utility (consumption) level in respective case, then we have

$$c_M^N(x; a) = w_M^N(a) - \tau x - r(x; a) \tag{3-19}$$

$$c_M^T(x; a) = w_M^T(a) - r(x; a) \tag{3-20}$$

where by our settings, only agents in normal teams are obliged to commute to the CBD.

3.3.4 Behavior of the Low-skilled Agents

The low-skilled agents are never motivated to be entrepreneur or middle manager in teams, thus the choice is between to be production worker, or to maintain self-employed, and if the low-skilled agents decide to be production worker, then choose which type of teams to join in.

Specifically, the low-skilled agents own six options: become production worker in two-layer team led by high-skilled agents, in two-layer team led by middle-skilled agents working at office or home, in three-layer team working at office or home, or maintain self-employed. They will earn $w_L^N(a)$, $w_L^T(a)$, $w_L^{Z_1}(a)$, $w_L^{Z_2}(a)$, $w_L^X(a)$ and $w_L^S = z_L$ in respective case.

Similarly, let $c_L^N(x; a)$, $c_L^T(x; a)$, $c_L^{Z_1}(x; a)$, $c_L^{Z_2}(x; a)$, $c_L^X(x; a)$ and c_L^S be the utility (consumption) level in respective case, then we have

$$c_L^N(x;a) = w_L^N(a) - \tau x - r(x;a) \tag{3-21}$$

$$c_L^T(x;a) = w_L^T(a) - r(x;a) \tag{3-22}$$

where by our settings, only agents in normal teams are obliged to commute to the CBD.

3.4 Equilibrium

In this subsection, we firstly give the equilibrium conditions that must be satisfied in equilibrium, then give the algorithm about how to solve the model, then clarify in detail about how to derive a (the offshoring pattern) in equilibrium, which will be shown to be the key to solve the whole system.

3.4.1 Equilibrium Conditions

In this subsection, we firstly introduce a condition such that which makes us focus solely on the decision of the high-skilled agents in the North, given the skill distribution in the South. Secondly, we derive several conditions that must be satisfied in equilibrium.

Look at equations (3-17) and (3-18), we realize that no middle-skilled agents will organize Z_1 or Z_2 if h_N (and thus h_T) is sufficiently large such that the profit derived from starting their own business (Z_1 or Z_2) is less than the offer provided by the high-skilled agents who organize Y, N or T.

Assumption 3.4.1 $h_N > \hat{h}(z_M, z_L) \equiv \frac{z_M - z_L}{z_M(1-z_L)}$

We will suppose that h_N is sufficiently large hereafter, and argue that the primary results we derived won't change even if h_N is not sufficiently large in the Appendix.

With respect to the equilibrium conditions, basically speaking as the spatial equilibrium condition and the land market clearing condition are essentially *local* conditions, they will be nearly the same as the conditions we derived in the Autarky case (in the chapter 2). In contrast, the free cross-occupational mobility condition and the labor market clearing condition are more *global* conditions, they have to be more modified.

Spatial Equilibrium Condition. In the South, for each category of low-skilled and middle-skilled agents, as they are freely moving from one location to another location, it has to be indifferent for them from relocating.

Thus, we have for each category of middle-skilled agents

$$\frac{dc_M^N(x;a)}{dx} = 0, \frac{dc_M^T(x;a)}{dx} = 0 \ and \ \frac{dc_M^S(x;a)}{dx} = 0 \tag{3-23}$$

meanwhile for each category of low-skilled agents

$$\frac{dc_L^N(x;a)}{dx} = 0, \frac{dc_L^T(x;a)}{dx} = 0 \ and \ \frac{dc_L^S(x;a)}{dx} = 0 \tag{3-24}$$

This further implies that for each category of agents, there is a location invariant utility level for all $x \in [0, +\infty)$:

$$c_M^N(x;a) = c_M^N(a), c_M^T(x;a) = c_M^T(a) \ and \ c_M^S(x;a) = c_M^S(a) \tag{3-25}$$

$$c_L^N(x;a) = c_L^N(a), c_L^T(x;a) = c_L^T(a) \ and \ c_L^S(x;a) = c_L^S(a) \tag{3-26}$$

Land Market Clearing Condition. In the South, the land is assigned through an auction market, where each agent bids a price and the bidder who bids the highest will obtain the land.

Literally, the bid that the agents are able to offer won't exceed the residual income after subtracting expenditures on commuting trips (if necessary) and consumptions from the gross income, thus we have that for each category of middle-skilled agents, the bid rent functions are given by

$$r_M^N(x;a) \equiv w_M^N(a) - c_M^N(a) - \tau x \tag{3-27}$$

$$r_M^T(a) \equiv w_M^T(a) - c_M^T(a) \tag{3-28}$$

and

$$r_M^S(a) \equiv w_M^S - c_M^S(a) \tag{3-29}$$

meanwhile for each category of low-skilled agents, the bid rent functions are given by

$$r_L^N(x;a) \equiv w_L^N(a) - c_L^N(a) - \tau x \tag{3-30}$$

$$r_L^T(a) \equiv w_L^T(a) - c_L^T(a) \tag{3-31}$$

and

$$r_L^S(a) \equiv w_L^S - c_L^S(a) \tag{3-32}$$

We firstly argue that the agents in local remote teams, and the self-employed won't bid higher than r_A (the opportunity cost of the land), the reason is because given the gross wage income offered at the market, any bid higher than r_A will just decline the utility (consumption) level but no any extra benefit is going to be obtained at all. Meanwhile, by the definition of r_A, any feasible bid rent can not be lower than r_A either. Hence, the bid rent of the agents in local remote teams and the self-employed will equal r_A.

Thus, the market rent curve turns out to be an envelope curve of the bid rent curves of agents in local normal teams:

$$r(x;a) = \max\{r_M^N(x;a), r_L^N(x;a)\} \tag{3-33}$$

Therefore, the land market is cleared if the amount of the lands where middle-skilled agent bids the highest is equal to the amount of middle-skilled agents, and the amount of the lands where low-skilled agent bids the highest is equal to the amount of low-skilled agents.

Free Cross-occupational Mobility Condition. We consider the free cross-occupational mobility condition in individual level, firstly it's straightforward to show that for any high-skilled agent $i \in \{1, 2, \ldots, H\}$

$$c_i(a_i, a_{-i}) = c_H^{a_i \in A}(a) \tag{3-34}$$

thus, we claim that a strategy profile a is a Nash Equilibrium (NE) if

$$\forall i, a_i' \in A : c_i(a_i, a_{-i}) \geq c_i(a_i', a_{-i}) \tag{3-35}$$

that is exactly a situation where no one is better off to unilaterally deviate from the current strategy.

On the other hand, with respect to the middle-skilled and low-skilled agents, they also freely choose to join in which type of teams (as long as there is offer provided by high-skilled agents), in equilibrium no one is better off to transfer to another type of teams.

Assumption 3.4.2 $\frac{H}{L} < h_I(1 - z_M)$

Lemma 3.4.1 *If the Assumption 3.4.2 holds, there will be always a portion of low-skilled agents who maintain self-employed.*

Intuitively speaking, one high-skilled agent will hire the most low-skilled agents if she organizes N or T (compare to hiring $1/[h_I(1-z_L)]$ if she organizes X), in another word, to the most there will be $H/[h_I(1-z_M)]$ low-skilled agents to be hired, if the Assumption 3.4.3 holds, which is $H/[h_I(1-z_M)] < L$, there will be always a portion of low-skilled agents who end up with being self-employed.

Assumption 3.4.3 $\frac{H}{M} < \frac{h_I(1-z_M)}{\gamma_T h_T(1-z_L)}$

Lemma 3.4.2 *If the Assumption 3.4.3 holds, there will be always a portion of middle-skilled agents who maintain self-employed.*

Intuitively speaking, one high-skilled agent will hire the most middle-skilled agents if she organizes T (compare to hiring $\gamma_N h_N(1-z_L)/[h_I(1-z_M)]$ if she organizes N), in another word, to the most there will be $H\gamma_T h_T(1-z_L)/[h_I(1-z_M)]$ middle-skilled agents to be hired, if the Assumption 3.4.3 holds, which is $H\gamma_T h_T(1-z_L)/[h_I(1-z_M)] < M$, there will be always a portion of middle-skilled agents who end up with being self-employed.

We therefore argue that in equilibrium, the offer provided to the low-skilled and the middle-skilled agents will just let the corresponding agent be indifferent to accept the offer or reject to maintain self-employed, that is the utility level must be equal.

We use the offer provided by entrepreneur to the middle-skilled agents in type T of team as an example to illustrate our argument above: if the offer is strictly larger than the self-employed's wage rate: $w_M^T > w_M^S = z_M$, then any firm could deviate to provide a new offer equal to $z_M + (w_M^T - z_M)/2$ to the remaining self-employed, the Assumption 3.4.3 will assure the deviation always occurs until $w_M^T = z_M$; on the other hand, if the offer is strictly less than the self-employed's wage rate: $w_M^T < w_M^S = z_M$, the low-skilled agents will reject the offer and maintain self-employed to earn z_M. In conclusion, $w_M^T = z_M$ in equilibrium.

Thus, we have under the free cross-occupational mobility condition, the utility level will be constant across working patterns, if we denote $c_L(a)$ and $c_M(a)$ as the constant level of the low-skilled and the middle-skilled agents respectively, we have

$$c_L(a) \equiv c_L^N(a) = c_L^T(a) = c_L^X(a) = c_L^S(a) \tag{3-36}$$

$$c_M(a) \equiv c_M^N(a) = c_M^T(a) = c_M^Y(a) = c_M^S(a) \tag{3-37}$$

Labor Market Clearing Condition. The supple of labor (at each category) should equal the demand of labor (at each category) in equilibrium.

We firstly argue that the labor market of the high-skilled agents will be always cleared, the reason is simple and because they essentially "offer" jobs to themselves, thus there is no discrepancy between the supply and demand.

Then, we turn to the labor market of the middle-skilled, and the low-skilled agents. Firstly, the high-skilled agents who organize teams hire corresponding type of middle-skilled and low-skilled agents in a fixed proportion:

$$L_N^d = \frac{H_N}{h_I(1-z_M)} \tag{3-38}$$

$$M_N^d = \frac{H_N \gamma_N h_N (1-z_L)}{h_I(1-z_M)} \tag{3-39}$$

and

$$L_T^d = \frac{H_T}{h_I(1-z_M)} \tag{3-40}$$

$$M_T^d = \frac{H_T \gamma_T h_T (1-z_L)}{h_I(1-z_M)} \tag{3-41}$$

Denote L_N^s, L_T^s, M_N^s and M_T^s as the labor supply at each category (the offer must be, or among the maximal to assure that the supply is positive). Then, we have that the labor markets of middle-skilled and low-skilled are cleared.

3.4.2 Algorithm

We solve the model analytically following the algorithm blow:

1. Derive $c_L^N(a)$ and $c_M^N(a)$. Use equation (3-27), (3-30) and the boundary conditions $r_L^N(M_N + L_N; a) = r_A$ and $r_L^N(M_N; a) = r_L^M(M_N; a)$, we have

$$c_L^N(a) = w_L^N(a) - \tau(M_N + L_N) - r_A \tag{3-42}$$

$$c_M^N(a) = w_M^N(a) - \tau(M_N + L_N) - r_A \tag{3-43}$$

where for simplicity, we assume that the commuting cost per unit of distance for middle-skilled and low-skilled is just the same[13].

[13] We assume that the commuting costs per unit of distance for skilled and unskilled agent are different in

Then, use equation (3-38), (3-39) and the labor market clearing conditions, we have

$$c_L^N(a) = w_L^N(a) - \tau H_N[\frac{1+\gamma_N h_N(1-z_L)}{h_I(1-z_M)}] - r_A \tag{3-44}$$

$$c_M^N(a) = w_M^N(a) - \tau H_N[\frac{1+\gamma_N h_N(1-z_L)}{h_I(1-z_M)}] - r_A \tag{3-45}$$

2. Derive $w_L^N(a)$, $w_M^N(a)$, $w_L^T(a)$ and $w_L^T(a)$. Use equation (3-27), (3-28), (3-36) and (3-37), we have

$$w_L^N(a) = z_L + \tau H_N[\frac{1+\gamma_N h_N(1-z_L)}{h_I(1-z_M)}] \tag{3-46}$$

$$w_M^N(a) = z_M + \tau H_N[\frac{1+\gamma_N h_N(1-z_L)}{h_I(1-z_M)}] \tag{3-47}$$

and

$$w_L^T(a) = z_L \tag{3-48}$$

$$w_M^T(a) = z_M \tag{3-49}$$

where the wage premiums per production worker and middle manager to organize local normal teams are equal and derived as

$$w_L^N(a) - w_L^T(a) = w_M^N(a) - w_M^T(a) = \tau H_N[\frac{1+\gamma_N h_N(1-z_L)}{h_I(1-z_M)}] \tag{3-50}$$

where the wage premium per employee, or the extra burden in average to organize normal team rather than remote team turns out to be increasing in τ, H_N, h_N and z_M, but decreasing in h_I and z_L.

Notice that one outstanding difference compared to the Autarky model in the chapter 2 is about the implication of h_N: in the Autarky case, the decline of h_N enlarges the team size of production worker, the wage premium per worker becomes higher, as well the burden in average to organize normal teams; however in the opening economy, the decline of h_N has no effect on the team size of production worker, but improves the local communication efficiency thus shrinks the team size of middle manager, the wage premium per worker becomes lower, as well the burden in average to organize normal teams. Counter-intuitively, in the opening economy, the improvement of local communication efficiency is anti- rather than pro-teleworking!

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the chapter 2, it's easy to show that the primary results we derived in the following won't change even if the commuting costs are different.

3. Derive a (the offshoring pattern), in another word H_N, H_T, H_X and H_S. We explain in detail about how to derive a blow.

4. Substitute a (or H_N) back into equations, and derive L_N, L_T, L_X, L_S, M_N, M_T, M_Y, M_S and other variables then.

3.4.3 Trade-offs among the Offshoring Patterns

We define $\Delta c_H^{a_i a_j}(a) \equiv c_H^{a_i}(a) - c_H^{a_j}(a)$ where $a_i, a_j \in A = \{N, T, X, Y, S\}$ but $a_i \neq a_j$ as the payoff differential of the entrepreneurs between any pair of strategies, thus we have for example

$$\begin{aligned}
\Delta c_H^{NT}(a) &= c_H^N(a) - c_H^T(a) \\
&= w_H^N(a) - w_H^T(a) \\
&= [\frac{z_H - w_L^N(a) - \gamma_N h_N(1-z_L)w_M^N(a)}{h_I(1-z_M)}] - [\frac{z_H - w_L^T(a) - \gamma_T h_T(1-z_L)w_M^T(a)}{h_I(1-z_M)}] \\
&= \frac{\gamma_T h_T(1-z_L)w_M^T(a) - \gamma_N h_N(1-z_L)w_M^N(a) - [w_L^N(a) - w_L^T(a)]}{h_I(1-z_M)} \\
&= \underbrace{\frac{(\gamma_T h_T - \gamma_N h_N)(1-z_L)w_M^T(a)}{h_I(1-z_M)}}_{The\ Thick\ Shield\ Effect} - \underbrace{\frac{\gamma_N h_N(1-z_L)[w_M^N(a) - w_M^T(a)]}{h_I(1-z_M)}}_{The\ (Middle-layer)\ Wage\ Premium\ Effect} \\
&- \underbrace{\frac{w_L^N(a) - w_L^T(a)}{h_I(1-z_M)}}_{The\ (Bottom-layer)\ Wage\ Premium\ Effect}
\end{aligned} \tag{3-51}$$

where firstly the entrepreneur will prefer N (T) over T (N) if $\Delta c_H^{NT}(a) > 0 (< 0)$; secondly, we decompose into three effects to reflect the trade-off face by the entrepreneur, the "Thick Shield Effect" inhibits teleworking, and the two "Wage Premium Effect(s)" play in the inverse direction, and promote teleworking.

Use the equation (3-46) to (3-50), we have further

$$\Delta c_H^{NT}(a) = \underbrace{\frac{(\gamma_T h_T - \gamma_N h_N)z_M(1-z_L)}{h_I(1-z_M)}}_{The\ Thick\ Shield\ Effect} - \underbrace{\tau H_N[\frac{1+\gamma_N h_N(1-z_L)}{h_I(1-z_M)}]^2}_{The\ (Composite)\ Wage\ Premium\ Effect} \tag{3-52}$$

Notice the role of the skill level of local elites in the host country, z_M. Firstly, as

$$\frac{\partial[\tau H_N[\frac{1+\gamma_N h_N(1-z_L)}{h_I(1-z_M)}]^2]}{\partial z_M} = \tau[\frac{1+\gamma_N h_N(1-z_L)}{h_I(1-z_M)}]^2[\frac{\partial H_N}{\partial z_M} + \frac{2H_N}{1-z_M}] \tag{3-53}$$

thus the "(Composite) Wage Premium Effect" is increasing in z_M if

$$\frac{\partial H_N}{\partial z_M}\frac{z_M}{H_N} > -\frac{2z_M}{1-z_M} \tag{3-54}$$

which implies that in terms of the "(Composite) Wage Premium Effect" the host country endowed with middle-skilled agents with higher skill level will be *less* likely incur remote teams if the equation (3-54) holds. Secondly, as

$$\frac{\partial[\frac{(\gamma_T h_T-\gamma_N h_N)z_M(1-z_L)}{h_I(1-z_M)}]}{\partial z_M} = \frac{(\gamma_T h_T-\gamma_N h_N)(1-z_L)}{h_I(1-z_M)^2} > 0 \tag{3-55}$$

the "Thick Shield Effect" is definitely increasing in z_M, which implies that in terms of the "Shield Effect" the host country endowed with middle-skilled agents with higher skill level will be *less* likely incur remote teams.

It's interesting to compare the role of the local elite in the opening model with the role in the Autarky model. In both models, the higher the skill level of the local elite, the less likely the remote teams are incurred.

However, the reason is different: in the Autarky model the skill level of the local elite is complementary to the local communication efficiency, we call it the "Span-of-control Effect" in the chapter 2, thus more knowledgeable local elite will welcome more normal team rather than remote team, because telecommunication within remote team is inferior to F2F communication within normal team; on the other hand, in the opening model, the local elite plays the role of middle manager and thus the effect on the trade-off between normal and remote team is quite different. This time higher z_M is subject to higher expenditure in middle layer from the perspective of northern entrepreneur, the reason is due to the inferior communication efficiency in remote team, the entrepreneur has to build a thicker shield, hire more local elites, that implies when the unit cost per middle manager z_M rises, the remote teams look less attractive compared to the normal teams. Although in the mechanism is totally different, more skilled local elite normally constitutes a factor that inhibits the proliferation of remote teams.

Then, although the entrepreneur owns five strategies in total, we argue in the Lemma 3.4.3 that the strategy Y is always dominated by the strategy X. The proof of it is given in the Appendix.

Lemma 3.4.3 *The high-skilled agents' strategy Y (organize two-layer team with southern* *middle-skilled agents) is always dominated by the strategy X (organize two-layer team with southern low-skilled agents).*

Thus, we only need to derive the residual five trade-off equations (otherwise it will be nine if we consider the strategy Y!): $\Delta c_H^{NX}(a)$, $\Delta c_H^{NS}(a)$, $\Delta c_H^{TX}(a)$, $\Delta c_H^{TS}(a)$ and $\Delta c_H^{XS}(a)$.

Firstly, we derive $\Delta c_H^{NX}(a)$:

$$\begin{aligned}\Delta c_H^{NX}(a) &= [w_H^N(a)] - [w_H^X(a)] \\ &= [\frac{z_H - w_L^N(a) - \gamma_N h_N(1-z_L)w_M^N(a)}{h_I(1-z_M)}] - [\frac{z_H - w_L^X(a)}{h_I(1-z_L)}] \\ &= \underbrace{\frac{(z_H - z_L)}{h_I(1-z_M)(1-z_L)}(z_M - z_L)}_{The\ Merit\ of\ the\ Shield} - \underbrace{\frac{\gamma_N h_N(1-z_L)}{h_I(1-z_M)}z_M}_{The\ Demerit\ of\ the\ Shield} \\ &- \underbrace{\tau H_N[\frac{1+\gamma_N h_N(1-z_L)}{h_I(1-z_M)}]^2}_{The\ (Composite)\ Wage\ Premium\ Effect} \end{aligned} \quad (3\text{-}56)$$

or we could combine the two shield effects into one composite one, then we have

$$\Delta c_H^{NX}(a) = \underbrace{\frac{(z_H - z_L)(z_M - z_L) - \gamma_N h_N z_M (1-z_L)^2}{h_I(1-z_M)(1-z_L)}}_{The\ (Composite)\ Shield\ Effect} - \underbrace{\tau H_N[\frac{1+\gamma_N h_N(1-z_L)}{h_I(1-z_M)}]^2}_{The\ (Composite)\ Wage\ Premium\ Effect} \quad (3\text{-}57)$$

Secondly, we derive $\Delta c_H^{NS}(a)$:

$$\begin{aligned}\Delta c_H^{NS}(a) &= [w_H^N(a)] - [w_H^S(a)] \\ &= [\frac{z_H - w_L^N(a) - \gamma_N h_N(1-z_L)w_M^N(a)}{h_I(1-z_M)}] - z_H \\ &= \frac{z_H - z_L - \gamma_N h_N z_M(1-z_L)}{h_I(1-z_M)} - z_H - \tau H_N[\frac{1+\gamma_N h_N(1-z_L)}{h_I(1-z_M)}]^2 \end{aligned} \quad (3\text{-}58)$$

Then, we derive $\Delta c_H^{TX}(a)$:

$$\begin{aligned}\Delta c_H^{TX}(a) &= [w_H^T(a)] - [w_H^X(a)] \\ &= [\frac{z_H - w_L^T(a) - \gamma_T h_T(1-z_L)w_M^T(a)}{h_I(1-z_M)}] - [\frac{z_H - w_L^X(a)}{h_I(1-z_L)}] \\ &= \frac{(z_H - z_L)(z_M - z_L) - \gamma_T h_T z_M(1-z_L)^2}{h_I(1-z_M)(1-z_L)} \end{aligned} \quad (3\text{-}59)$$

Then, we derive $\Delta c_H^{TS}(a)$:

$$\begin{aligned}\Delta c_H^{TS}(a) &= [w_H^T(a)] - [w_H^S(a)] \\ &= [\frac{z_H - w_L^T(a) - \gamma_T h_T(1-z_L)w_M^T(a)}{h_I(1-z_M)}] - z_H \\ &= \frac{z_H - z_L - \gamma_T h_T z_M(1-z_L)}{h_I(1-z_M)} - z_H \end{aligned} \tag{3-60}$$

Finally, we derive $\Delta c_H^{XS}(a)$:

$$\begin{aligned}\Delta c_H^{XS}(a) &= [w_H^X(a)] - [w_H^S(a)] \\ &= [\frac{z_H - w_L^X(a)}{h_I(1-z_L)}] - z_H \\ &= [\frac{z_H - z_L}{h_I(1-z_L)}] - z_H \end{aligned} \tag{3-61}$$

3.4.4 Offshoring Patterns in Equilibrium

In this subsection, we derive the offshoring patterns a in equilibrium, in a sense no one wants to deviate from the current strategy to the other feasible ones.

Notice that the equations (3-52), and (3-56) to (3-61) imply that the trade-off functions not involving the strategy N are independent on a (or H_N), which allows us to isolate the strategic strategy N from those non-strategic strategies X, T and S. Thus, in the following the discussion follows two steps; firstly, we compare the non-strategic strategies, and see which one dominates the others; then, we compare that dominant non-strategic strategy to the strategic strategy N, and check what kind of offshoring patterns will emerge in the equilibrium.

Non-strategic Strategies' Dominance. First of all, we have that the strategy T dominates X and S if $\Delta c_H^{TX} > 0$ and $\Delta c_H^{TS} > 0$ hold simultaneously:

$$z_M > \hat{z}_M(\gamma_T h_T) \tag{3-62}$$

where

$$\hat{z}_M(\gamma_T h_T) \equiv \frac{(z_H - z_L)z_L}{z_H - z_L - \gamma_T h_T(1-z_L)^2} \tag{3-63}$$

and

$$h_I < f(z_M; \gamma_T h_T) \tag{3-64}$$

where

$$f(z_M;\gamma_T h_T) \equiv \frac{z_H - z_L - \gamma_T h_T z_M(1-z_L)}{z_H(1-z_M)} \tag{3-65}$$

as $z_M \in (z_L, z_H)$ the boundary values of function f are derived at $z_M \to z_L$ and $z_M \to z_H$:

$$f(z_L;\gamma_T h_T) = \frac{z_H - z_L - \gamma_T h_T z_L(1-z_L)}{z_H(1-z_L)} \tag{3-66}$$

$$f(z_H;\gamma_T h_T) = \frac{z_H - z_L - \gamma_T h_T z_H(1-z_L)}{z_H(1-z_H)} \tag{3-67}$$

in terms of the shape of the curve f, we learn from its first-order and second-order derivatives:

$$\frac{\partial f(z_M;\gamma_T h_T)}{\partial z_M} = \frac{z_H - z_L - \gamma_T h_T(1-z_L)}{z_H(1-z_M)^2} \tag{3-68}$$

$$\frac{\partial^2 f(z_M;\gamma_T h_T)}{\partial z_M^2} = 2[\frac{z_H - z_L - \gamma_T h_T(1-z_L)}{z_H(1-z_M)^3}] \tag{3-69}$$

thus the curve f is either increasing and convex if

$$\gamma_T h_T < \frac{z_H - z_L}{1-z_L} \tag{3-70}$$

or decreasing and concave if

$$\gamma_T h_T > \frac{z_H - z_L}{1-z_L} \tag{3-71}$$

In addition, the strategy X dominates S if $\Delta c_H^{XS} > 0$:

$$h_I < \hat{h}(z_H, z_L) \tag{3-72}$$

where

$$\hat{h}(z_H, z_L) \equiv \frac{z_H - z_L}{z_H(1-z_L)} \tag{3-73}$$

Then, in order to draw figures, we check the relation between $\hat{h}(z_H, z_L)$ and the boundary values of function f. It's easy to show that (1) $\hat{h}(z_H, z_L) > f(z_L;\gamma_T h_T)$; (2) $f(z_L;\gamma_T h_T) > 0$ if

$$\gamma_T h_T < \frac{z_H - z_L}{z_L(1-z_L)} \tag{3-74}$$

Table 3.5: Non-strategic Strategies' Dominance

	$f' > 0$ or not	$\hat{z}_M(\gamma_T h_T) < z_H$ or not	$\hat{h}(z_H, z_L) > f(z_H; \gamma_T h_T)$ or not	$f(z_H; \gamma_T h_T) > 0$ or not
Case 1	Increasing	Yes	No	Yes
Case 2	Increasing	No	Yes	Yes
Case 3	Decreasing	No	Yes	Yes
Case 4	Decreasing	No	Yes	No

(3) $f(z_H; \gamma_T h_T) > \hat{h}(z_H, z_L) >$ if

$$\gamma_T h_T < \frac{(z_H - z_L)^2}{z_H(1 - z_L)^2} \tag{3-75}$$

and (4) $f(z_H; \gamma_T h_T) > 0$ if

$$\gamma_T h_T < \frac{z_H - z_L}{z_H(1 - z_L)} \tag{3-76}$$

In conclusion, we divide the situation into four cases in terms of the level of $\gamma_T h_T$ (see Table 3.5):

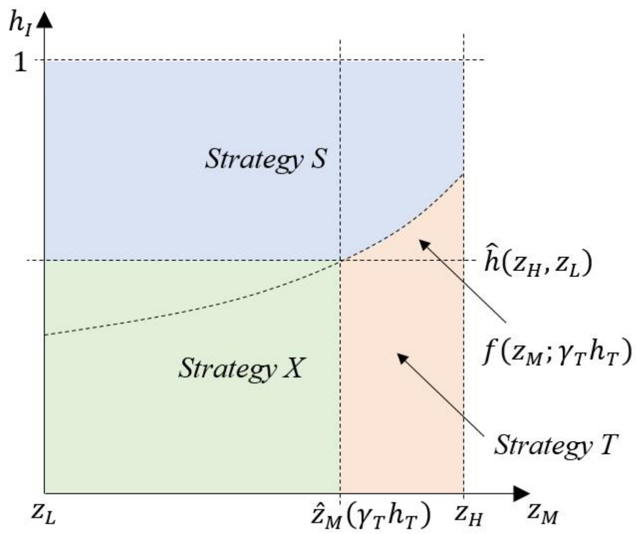

Figure 3.3: The case 1 (when $\gamma_T h_T < \frac{(z_H - z_L)^2}{z_H(1-z_L)^2}$)

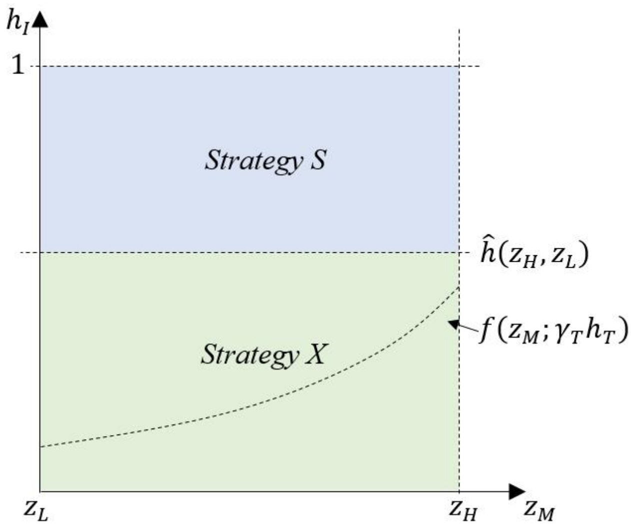

Figure 3.4: The case 2 (when $\frac{(z_H - z_L)^2}{z_H(1-z_L)^2} < \gamma_T h_T < \frac{z_H - z_L}{1 - z_L}$)

We have firstly that the conditions $\hat{z}_M(\gamma_T h_T) < z_H$ and $\hat{h}(z_H, z_L) < f(z_H; \gamma_T h_T)$ are the same, and equivalent to

$$\gamma_T h_T < \frac{(z_H - z_L)^2}{z_H(1 - z_L)^2} \tag{3-77}$$

then, we show as long as the condition (3-77) holds, the function f must be increasing in terms of z_M as $(z_H - z_L)/[z_H(1 - z_L)] < 1$, we thus derive Figure 3.3; secondly, We have that the

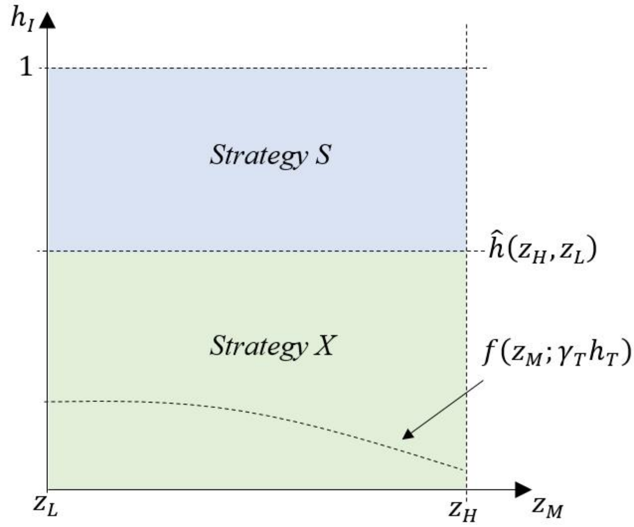

Figure 3.5: The case 3 (when $\frac{z_H - z_L}{1 - z_L} < \gamma_T h_T < \frac{z_H - z_L}{z_H(1 - z_L)}$)

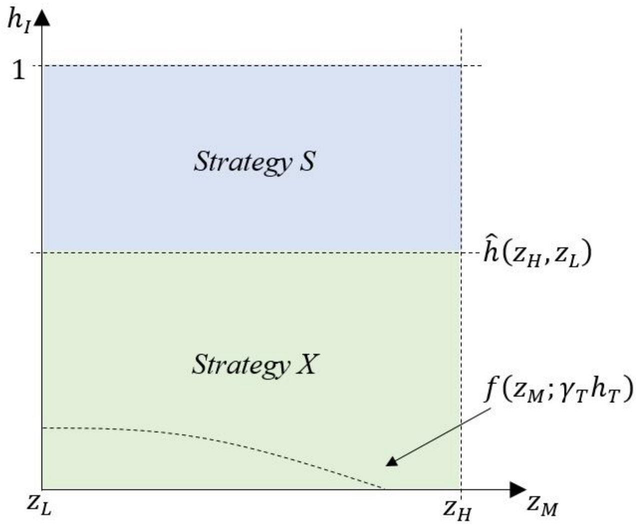

Figure 3.6: The case 4 (when $\frac{z_H - z_L}{z_H(1 - z_L)} < \gamma_T h_T < \frac{z_H - z_L}{z_L(1 - z_L)}$)

conditions $\hat{z}_M(\gamma_T h_T) > z_H$ and $\hat{h}(z_H, z_L) > f(z_H; \gamma_T h_T)$ are the same, and equivalent to

$$\gamma_T h_T > \frac{(z_H - z_L)^2}{z_H(1 - z_L)^2} \tag{3-78}$$

then, if further the function f is increasing in terms of z_M, we derive Figure 3.4; thirdly, if further the function f is decreasing and $f(z_H; \gamma_T h_T)$ is positive we derive Figure 3.5; fourthly, if the function f is decreasing but $f(z_H; \gamma_T h_T)$ is negative we derive Figure 3.6.

Lemma 3.4.4 *One necessary condition of that the strategy T dominates the strategy X and S in terms of $\gamma_T h_T$, z_H and z_L is derived as*

$$\gamma_T h_T < \frac{(z_H - z_L)^2}{z_H(1 - z_L)^2} \tag{3-79}$$

The Lemma 3.4.4 is saying that in order to make remote teams feasible in the South, a low enough $\gamma_T h_T$ is necessary, that's intuitive; besides, look at the Figure 3.3, which is the figure that satisfies the condition (3-79) laid out in the Lemma 3.4.4, a low enough h_I and high enough z_M are also necessary (they're not sufficient because we're still not comparing the non-strategic strategy T to the strategic strategy N!), a low enough h_I is somehow intuitive as well, but the argument that higher skill level of local elites will promote the emergence of local remote teams is much more informative.

The reason behind it is not that complicated, it's essentially due to the role of the middle manager in our specific knowledge hierarchical team. Refer to the equation (3-59), we decompose Δc_H^{TX} into two parts:

$$\Delta c_H^{TX} = \underbrace{\frac{(z_H - z_L)}{h_I(1-z_M)(1-z_L)}(z_M - z_L)}_{The\ Merit\ of\ the\ Shield} - \underbrace{\frac{\gamma_T h_T(1-z_L)}{h_I(1-z_M)} z_M}_{The\ Demerit\ of\ the\ Shield} \tag{3-80}$$

meanwhile we have

$$\frac{\partial[\frac{(z_H - z_L)}{h_I(1-z_M)(1-z_L)}(z_M - z_L)]}{\partial z_M} = \frac{z_H - z_L}{h_I(1-z_M)^2} > 0 \tag{3-81}$$

and

$$\frac{\partial[\frac{\gamma_T h_T(1-z_L)}{h_I(1-z_M)} z_M]}{\partial z_M} = \frac{\gamma_T h_T(1-z_L)}{h_I(1-z_M)^2} > 0 \tag{3-82}$$

thus a higher z_M will increase both the merit and demerit of the shield, which one dominates depends on whether $\gamma_T h_T < (z_H - z_L)/(1 - z_L)$ or not: if $\gamma_T h_T < (z_H - z_L)/(1 - z_L)$, the increase of the merit exceeds the increase of the demerit, otherwise, the increase of the demerit exceeds the increase of the merit.

As the existence of the competition among non-strategic competitions, the strategy T dominates only if $\gamma_T h_T < (z_H - z_L)/(1 - z_L)$, that is when the increase of the merit exceeds the increase of the demerit of the shield. In another word, although a higher z_M shields the entrepreneur more from the routine task and thus enlarge the team size, meanwhile increase the wage expenditure on the shield, as long as the local telecommunication efficiency maintains high enough, the positive span-of-control effect will exceed the extra burden of wage expenditure.

In the following, we deliberately choose to focus on the case 1 where all three non-strategic strategies T, X and S are feasible (see Figure 3.3), and we check how they compete with the strategy N.

The discussion further follows two steps, firstly we consider when the cross-border communication is non-prohibitive, that occurs when $h_I < \hat{h}(z_H, z_L)$; then we consider when the cross-border communication is approximately[14] prohibitive, that occurs when $h_I > \hat{h}(z_H, z_L)$.

Non-prohibitive Cross-border Communication Friction. Look at the Figure 3.3, when $h_I < \hat{h}(z_H, z_L)$, the strategy S is dominated such that no one will deviate to it; furthermore, the strategy T dominates X if $z_M > \hat{z}_M(\gamma_T h_T)$, the strategy X dominates T if $z_M < \hat{z}_M(\gamma_T h_T)$.

[14] We call it approximately prohibitive, because as shown in the Figure 3.3, even if h_I is that high, as long as z_M is high enough, the strategy T is still feasible.

Firstly we check the situation when $h_I < \hat{h}(z_H, z_L)$ and $z_M > \hat{z}_M(\gamma_T h_T)$, three kinds of equilibria might emerge. First is when $H_T = H$ and $H_N = 0$, it's a Nash equilibrium if no agent is marginally better off through unilaterally deviating from T to N, with respect to any agent i it holds if

$$c_i(T, a_{-i}) \geq c_i(N, a_{-i}) \tag{3-83}$$

where specifically

$$a_{-i} = (\underbrace{T, \ldots, T}_{H-1 \ in \ total}) \tag{3-84}$$

Use the equation (3-34) and the definition of Δc_H^{NT}, we have that the condition (83) is equivalent to

$$\Delta c_H^{NT}(H_N = 0) \leq 0 \tag{3-85}$$

However, as

$$\Delta c_H^{NT}(H_N = 0) = \frac{(\gamma_T h_T - \gamma_N h_N) z_M (1 - z_L)}{h_I (1 - z_M)} > 0 \tag{3-86}$$

the situation when $H_T = H$ and $H_N = 0$ will never be a Nash equilibrium: the high-skilled agent will always be better off through deviating from T to N.

Second is when $H_N = H$ and $H_T = 0$, similarly it's a Nash equilibrium if no agent is marginally better off through unilaterally deviating from N to T, with respect to any agent i it holds if

$$c_i(T, a_{-i}) \leq c_i(N, a_{-i}) \tag{3-87}$$

where specifically

$$a_{-i} = (\underbrace{N, \ldots, N}_{H-1 \ in \ total}) \tag{3-88}$$

Use the equation (3-34) and the definition of Δc_H^{NT}, we have that the condition (3-87) is equivalent to

$$\Delta c_H^{NT}(H_N = H) \geq 0 \tag{3-89}$$

that holds if

$$\tau H \leq \Phi(z_M; h_I, \gamma_T h_T) \tag{3-90}$$

where

$$\Phi(z_M; h_I, \gamma_T h_T) \equiv \frac{h_I(\gamma_T h_T - \gamma_N h_N)(1 - z_L)}{[1 + \gamma_N h_N (1 - z_L)]^2}(-z_M^2 + z_M) \tag{3-91}$$

where the curve $\Phi(z_M; h_I, \gamma_T h_T)$ is a downward parabola with the symmetric axis at $z_M = 1/2$, there're two real roots with $z_M = 0$ and $z_M = 1$.

We derive the values of $\Phi(z_M; h_I, \gamma_T h_T)$ at $z_M = 1/2$, $z_M = \hat{z}_M(\gamma_T h_T)$ and $z_M = z_H$ respectively

$$\Phi(\frac{1}{2}; h_I, \gamma_T h_T) = \frac{h_I(\gamma_T h_T - \gamma_N h_N)(1 - z_L)}{4[1 + \gamma_N h_N(1 - z_L)]^2} \tag{3-92}$$

$$\Phi(\hat{z}_M(\gamma_T h_T); h_I, \gamma_T h_T) = \frac{h_I[z_H - z_L - \gamma_T h_T(1 - z_L)](\gamma_T h_T - \gamma_N h_N)(z_H - z_L)z_L(1 - z_L)^2}{[z_H - z_L - \gamma_T h_T(1 - z_L)^2]^2[1 + \gamma_N h_N(1 - z_L)]^2} \tag{3-93}$$

and

$$\Phi(z_H; h_I, \gamma_T h_T) = \frac{h_I(\gamma_T h_T - \gamma_N h_N)z_H(1 - z_H)(1 - z_L)}{[1 + \gamma_N h_N(1 - z_L)]^2} \tag{3-94}$$

Third is a mixed case when $H_N > 0$ and $H_T > 0$, we denote H_N^{NT} as the interior solution such that it satisfies the following equation:

$$\Delta c_H^{NT}(H_N = H_N^{NT}) = 0 \tag{3-95}$$

then we have

$$H_N^{NT} = \frac{\Phi(z_M; h_I, \gamma_T h_T)}{\tau} \tag{3-96}$$

This situation emerges if the condition that induces corner solutions doesn't hold, which is

$$\Delta c_H^{NT}(H_N = H) < 0 \tag{3-97}$$

that holds if

$$\tau H > \Phi(z_M; h_I, \gamma_T h_T) \tag{3-98}$$

Notice also that given the condition (3-79), we have no idea about whether $\hat{z}_M(\gamma_T h_T) < 1/2$ or not[15].

We derive $\hat{z}_M(\gamma_T h_T) < 1/2$ if and only if

$$\gamma_T h_T < \frac{(z_H - z_L)(1 - 2z_L)}{(1 - z_L)^2} \tag{3-99}$$

We also derive that the RHS of the condition (3-99) will be smaller than the RHS of the condition (3-79) if and only if

$$z_H > \frac{1}{2} \tag{3-100}$$

[15]Unless $z_H < 1/2$, in that case obviously $\hat{z}_M(\gamma_T h_T)$ will be less than $1/2$, or $z_L > 1/2$, in that case obviously $\hat{z}_M(\gamma_T h_T)$ will be more than $1/2$, otherwise it could be either more or less than, or equal to $1/2$.

Secondly we check the situation when $h_I < \hat{h}(z_H, z_L)$ and $z_M < \hat{z}_M(\gamma_T h_T)$, three kinds of equilibria might emerge. First is when $H_X = H$ and $H_N = 0$, it's a Nash equilibrium if no agent is marginally better off through unilaterally deviating from X to N, with respect to any agent i it holds if

$$c_i(X, a_{-i}) \geq c_i(N, a_{-i}) \tag{3-101}$$

where specifically

$$a_{-i} = (\underbrace{X, \ldots, X}_{H-1 \ in \ total}) \tag{3-102}$$

Use the equation (3-34) and the definition of Δc_H^{NX}, we have that the condition (3-101) is equivalent to

$$\Delta c_H^{NX}(H_N = 0) \leq 0 \tag{3-103}$$

that holds if

$$z_M \leq \hat{z}_M(\gamma_N h_N) \tag{3-104}$$

where as we assume above that $\gamma_N h_N < \gamma_T h_T$ and the function $\hat{z}_M$ is increasing in terms of the augment, thus $\hat{z}_M(\gamma_N h_N) < \hat{z}_M(\gamma_T h_T)$, and the situation when $H_X = H$ and $H_N = 0$ as an equilibrium is feasible.

Second is when $H_N = H$ and $H_X = 0$, similarly it's a Nash equilibrium if no agent is marginally better off through unilaterally deviating from N to X, with respect to any agent i it holds if

$$c_i(X, a_{-i}) \leq c_i(N, a_{-i}) \tag{3-105}$$

where specifically

$$a_{-i} = (\underbrace{N, \ldots, N}_{H-1 \ in \ total}) \tag{3-106}$$

Use the equation (3-34) and the definition of Δc_H^{NX}, we have that the condition (3-105) is equivalent to

$$\Delta c_H^{NX}(H_N = H) \geq 0 \tag{3-107}$$

that holds if

$$\tau H \leq \Psi(z_M; h_I) \tag{3-108}$$

where

$$\begin{aligned}\Psi(z_M;h_I) \;\equiv\; & \frac{h_I}{[1+\gamma_N h_N(1-z_L)]^2(1-z_L)} \\ & \{-[z_H - z_L - \gamma_N h_N(1-z_L)^2]z_M^2 \\ & +[(z_H-z_L)(1+z_L) - \gamma_N h_N(1-z_L)^2]z_M \\ & -(z_H-z_L)z_L\} \end{aligned} \quad (3\text{-}109)$$

where as $\hat{z}_M(\gamma_N h_N) > 0$, $\Psi(z_M;h_I)$ is also a downward parabola, then through factorization we have

$$\begin{aligned}\Psi(z_M;h_I) \;=\; & \frac{h_I}{[1+\gamma_N h_N(1-z_L)]^2(1-z_L)}(1-z_M) \\ & \{[z_H - z_L - \gamma_N h_N(1-z_L)^2]z_M - (z_H-z_L)z_L\} \end{aligned} \quad (3\text{-}110)$$

thus we have two real roots as $z_M = \hat{z}_M(\gamma_N h_N)$ and $z_M = 1$, the symmetric axis will be at $z_M = [1+\hat{z}_M(\gamma_N h_N)]/2 > 1/2$.

We derive the values of $\Psi(z_M;h_I)$ at $z_M = [1+\hat{z}_M(\gamma_N h_N)]/2$, $z_M = \hat{z}_M(\gamma_T h_T)$ and $z_M = z_H$ respectively

$$\Psi(\frac{1+\hat{z}_M(\gamma_N h_N)}{2};h_I) = \frac{h_I(1-z_L)}{4[1+\gamma_N h_N(1-z_L)]^2}\frac{[z_H - z_L - \gamma_N h_N(1-z_L)]^2}{z_H - z_L - \gamma_N h_N(1-z_L)^2} \quad (3\text{-}111)$$

$$\Psi(\hat{z}_M(\gamma_T h_T);h_I) = \frac{h_I[z_H - z_L - \gamma_N h_N(1-z_L)^2]}{[1+\gamma_N h_N(1-z_L)]^2(1-z_L)}[1-\hat{z}_M(\gamma_T h_T)][\hat{z}_M(\gamma_T h_T) - \hat{z}_M(\gamma_N h_N)] \quad (3\text{-}112)$$

and

$$\Psi(z_H;h_I) = \frac{h_I[z_H - z_L - \gamma_N h_N(1-z_L)^2](1-z_H)[z_H - \hat{z}_M(\gamma_N h_N)]}{[1+\gamma_N h_N(1-z_L)]^2(1-z_L)} \quad (3\text{-}113)$$

We show in the following several relations about the curve Φ and Ψ:

Firstly, use the equation (3-93) and (3-112), we have

$$\Psi(\hat{z}_M(\gamma_T h_T);h_I) = \Phi(\hat{z}_M(\gamma_T h_T);h_I,\gamma_T h_T) \quad (3\text{-}114)$$

which implies that the curve Φ and Ψ interacts at $\hat{z}_M(\gamma_T h_T)$.

Secondly, use the equation (3-92) and (3-111), we have

$$\Psi(\frac{1+\hat{z}_M(\gamma_N h_N)}{2};h_I)/\Phi(\frac{1}{2};h_I,\gamma_T h_T) > 1 \quad (3\text{-}115)$$

if and only if

$$\gamma_T h_T < \gamma_N h_N + \frac{[z_H - z_L - \gamma_N h_N (1 - z_L)]^2}{z_H - z_L - \gamma_N h_N (1 - z_L)^2} \tag{3-116}$$

Thirdly, use the equation (3-94) and (3-113), we have

$$\Psi(z_H; h_I)/\Phi(z_H; h_I, \gamma_T h_T) > 1 \tag{3-117}$$

if and only if

$$\gamma_T h_T < \frac{(z_H - z_L)^2}{z_H (1 - z_L)^2} \tag{3-118}$$

which holds exactly as the condition (3-79) implies.

Third is a mixed case when $H_N > 0$ and $H_X > 0$, we denote H_N^{NX} as the interior solution such that it satisfies the following equation:

$$\Delta c_H^{NX}(H_N = H_N^{NX}) = 0 \tag{3-119}$$

then we have

$$H_N^{NX} = \frac{\Psi(z_M; h_I)}{\tau} \tag{3-120}$$

This situation emerges if the condition that induces corner solutions doesn't hold, which is

$$\Delta c_H^{NX}(H_N = H) < 0 \; and \; \Delta c_H^{NX}(H_N = 0) > 0 \tag{3-121}$$

that holds if

$$\tau H > \Psi(z_M; h_I) \; and \; z_M > \hat{z}_M(\gamma_N h_N) \tag{3-122}$$

To conclude, we derive four equilibria (offshoring patterns) when the cross-border communication is non-prohibitive as the following: (1) All the northern high-skilled agents choose the strategy X, namely organize two-layer teams with the southern low-skilled agents; (2) All the northern high-skilled agents choose the strategy N, namely organize three-layer teams with the southern low-skilled and middle-skilled agents with whom organized in traditional way; (3) The northern high-skilled agents choose the strategy N or X simultaneously; (4) the northern high-skilled agents choose the strategy N or T simultaneously. We denote them as E_X, E_N, E_{NX} and E_{NT} in order.

We draw figures in $(z_M, \tau H)$ space to highlight the area within which each equilibrium offshoring pattern emerges (see Figure 3.7 and 3.8). Two figures differ in terms of whether $\hat{z}_M(\gamma_T h_T) < 1/2$ or not: Figure 3.7 exhibits equilibrium offshoring patterns when $\hat{z}_M(\gamma_T h_T) <$

1/2, in contrast Figure 3.8 exhibits equilibrium offshoring patterns when $\hat{z}_M(\gamma_T h_T) > 1/2$. Although the implications are trivially different between two figures, there is no any qualitative discrepancy.

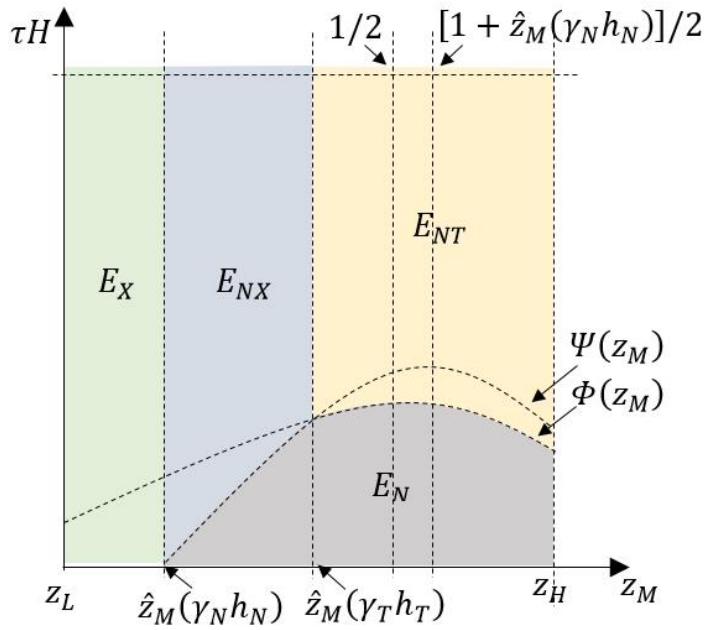

Figure 3.7: Equilibrium offshoring patterns when $h_I < \hat{h}(z_H, z_L)$ and $\gamma_T h_T < \frac{(z_H - z_L)(1-2z_L)}{(1-z_L)^2}$

Prohibitive Cross-border Communication Friction. Look at the Figure 3.3, when $h_I > \hat{h}(z_H, z_L)$, the strategy X is dominated such that no one will deviate to it; furthermore, the strategy T dominates S if $z_M > \tilde{z}_M(\gamma_T h_T)$, the strategy S dominates T if $z_M < \tilde{z}_M(\gamma_T h_T)$, where

$$\tilde{z}_M(\gamma_T h_T) \equiv \frac{h_I z_H - (z_H - z_L)}{h_I z_H - \gamma_T h_T (1 - z_L)} \tag{3-123}$$

where both the denominator and the numerator of $\tilde{z}_M(\gamma_T h_T)$ are positive[16].

Firstly we check the situation when $h_I > \hat{h}(z_H, z_L)$ and $z_M < \tilde{z}_M(\gamma_T h_T)$, three kinds of equilibria might emerge. First is when $H_S = H$ and $H_N = 0$, it's a Nash equilibrium if no agent is marginally better off through unilaterally deviating from S to N, with respect to any agent i it holds if

$$c_i(S, a_{-i}) \geq c_i(N, a_{-i}) \tag{3-124}$$

where specifically

$$a_{-i} = (\underbrace{S, \ldots, S}_{H-1 \ in \ total}) \tag{3-125}$$

[16]Use the constraints of h_I and $\gamma_T h_T$, we can easily derive the results.

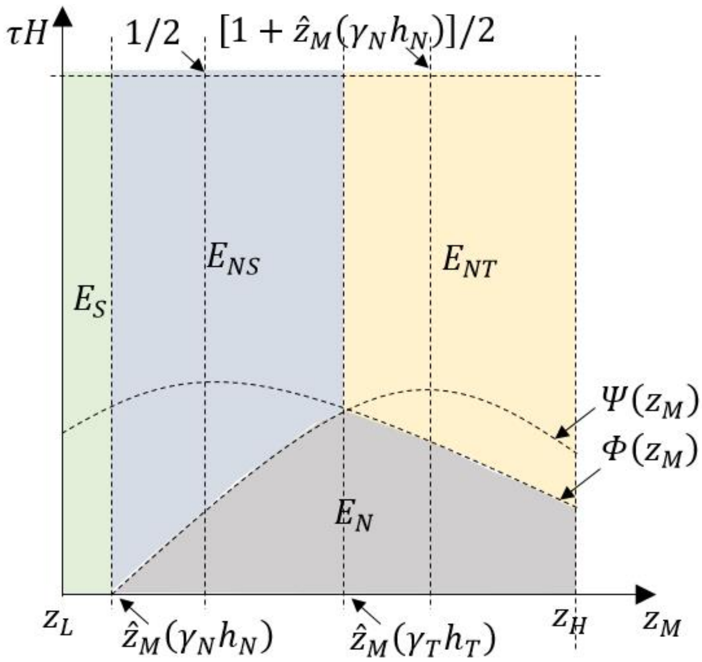

Figure 3.8: Equilibrium offshoring patterns when $h_I < \hat{h}(z_H, z_L)$ and $\frac{(z_H - z_L)(1-2z_L)}{(1-z_L)^2} < \gamma_T h_T < \frac{(z_H - z_L)^2}{z_H(1-z_L)^2}$

Use the equation (3-34) and the definition of Δc_H^{NS}, we have that the condition (3-124) is equivalent to

$$\Delta c_H^{NS}(H_N = 0) \leq 0 \tag{3-126}$$

that holds if

$$z_M \leq \tilde{z}_M(\gamma_N h_N) \tag{3-127}$$

where as we assume above that $\gamma_N h_N < \gamma_T h_T$ and the function $\tilde{z}_M$ is increasing in terms of the augment, thus $\tilde{z}_M(\gamma_N h_N) < \tilde{z}_M(\gamma_T h_T)$, and the situation when $H_S = H$ and $H_N = 0$ as an equilibrium is feasible.

Second is when $H_N = H$ and $H_S = 0$, similarly it's a Nash equilibrium if no agent is marginally better off through unilaterally deviating from N to S, with respect to any agent i it holds if

$$c_i(S, a_{-i}) \leq c_i(N, a_{-i}) \tag{3-128}$$

where specifically

$$a_{-i} = (\underbrace{N, \dots, N}_{H-1\ in\ total}) \tag{3-129}$$

Use the equation (3-34) and the definition of Δc_H^{NS}, we have that the condition (3-124) is equivalent to

$$\Delta c_H^{NS}(H_N = H) \geq 0 \tag{3-130}$$

that holds if

$$\tau H \leq K(z_M; h_I) \tag{3-131}$$

where

$$\begin{aligned} K(z_M; h_I) \quad \equiv \quad & \frac{h_I}{[1 + \gamma_N h_N(1 - z_L)]^2}(1 - z_M) \\ & \{z_H - z_L - h_I z_H + [h_I z_H - \gamma_N h_N(1 - z_L)]z_M\} \end{aligned} \tag{3-132}$$

where as $h_I z_H - \gamma_N h_N(1 - z_L) > 0$, the $K(z_M; h_I)$ is a downward parabola, and we have two real roots as $z_M = \tilde{z}_M(\gamma_N h_N)$ and $z_M = 1$, the symmetric axis will be at $z_M = [1 + \tilde{z}_M(\gamma_N h_N)]/2 > 1/2$.

Third is a mixed case when $H_N > 0$ and $H_S > 0$, we denote H_N^{NS} as the interior solution such that it satisfies the following equation:

$$\Delta c_H^{NS}(H_N = H_N^{NS}) = 0 \tag{3-133}$$

then we have

$$H_N^{NX} = \frac{K(z_M; h_I)}{\tau} \tag{3-134}$$

This situation emerges if the condition that induces corner solutions doesn't hold, which is

$$\Delta c_H^{NS}(H_N = H) < 0 \; and \; \Delta c_H^{NS}(H_N = 0) > 0 \tag{3-135}$$

that holds if

$$\tau H > K(z_M; h_I) \; and \; z_M > \tilde{z}_M(\gamma_N h_N) \tag{3-136}$$

The analysis about the situation when $h_I > \hat{h}(z_H, z_L)$ and $z_M > \tilde{z}_M(\gamma_T h_T)$ is basically the same as the situation when $h_I < \hat{h}(z_H, z_L)$ and $z_M > \hat{z}_M(\gamma_T h_T)$ except that the boundary value $\hat{z}_M(\gamma_T h_T)$ is substituted by $\tilde{z}_M(\gamma_T h_T)$

Notice also that given the condition (3-79), we have no idea whether $\tilde{z}_M(\gamma_T h_T) < 1/2$ or not. We derive $\tilde{z}_M(\gamma_T h_T) < 1/2$ if and only if

$$\gamma_T h_T < \frac{2(z_H - z_L) - h_I z_H}{1 - z_L} \tag{3-137}$$

as $h_I > \hat{h}(z_H, z_L)$, we have

$$\gamma_T h_T < \frac{2(z_H - z_L) - h_I z_H}{1 - z_L} < \frac{(z_H - z_L)(1 - 2z_L)}{(1 - z_L)^2} \tag{3-138}$$

where the RHS of the condition (3-138) is same as the RHS of the condition (3-99), thus similarly the RHS of the condition (3-138) will be smaller than the RHS of the condition (3-79) if and only if

$$z_H > \frac{1}{2} \tag{3-139}$$

To conclude, we derive four equilibria (offshoring patterns) when the cross-border communication is prohibitive as the following: (1) All the northern high-skilled agents choose the strategy S, namely work on their own; (2) All the northern high-skilled agents choose the strategy N, namely organize three-layer teams with the southern low-skilled and middle-skilled agents with whom organized in traditional way; (3) The northern high-skilled agents choose the strategy N or S simultaneously; (4) the northern high-skilled agents choose the strategy N or T simultaneously. The second and the fourth have been denoted as E_N and E_{NT}, we denote newly the first and the third as E_S and E_{NS}.

We draw figures in $(z_M, \tau H)$ space to highlight the area within which each equilibrium offshoring pattern emerges (see Figure 3.9 and 3.10).

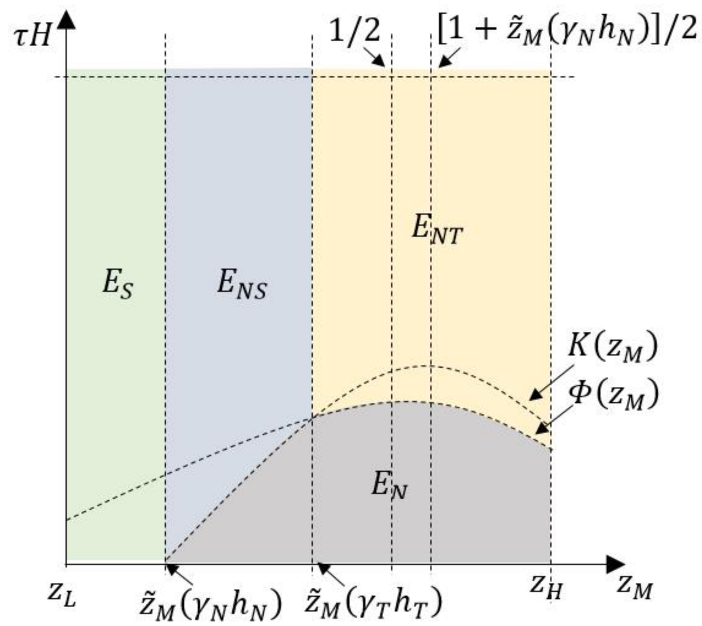

Figure 3.9: Equilibrium offshoring patterns when $h_I > \hat{h}(z_H, z_L)$ and $\gamma_T h_T < \frac{(z_H - z_L)(1-2z_L)}{(1-z_L)^2}$

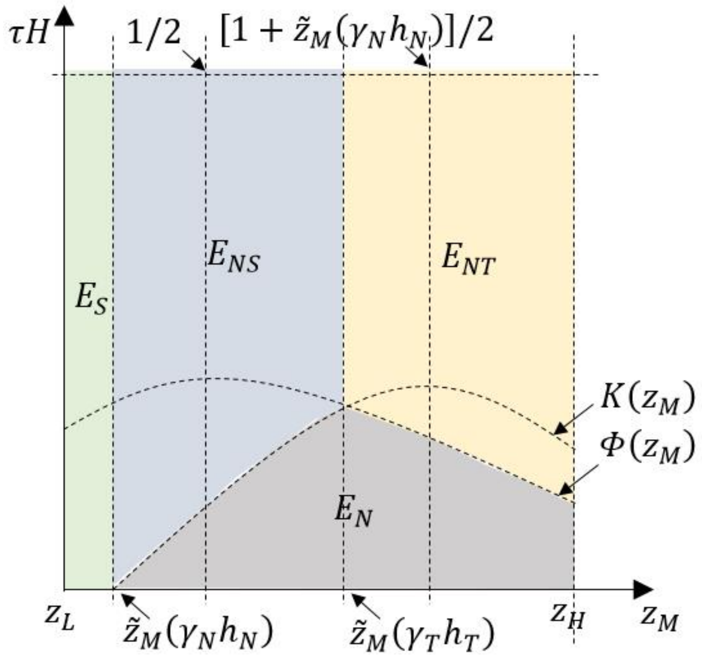

Figure 3.10: Equilibrium offshoring patterns when $h_I > \hat{h}(z_H, z_L)$ and $\frac{(z_H-z_L)(1-2z_L)}{(1-z_L)^2} < \gamma_T h_T < \frac{(z_H-z_L)^2}{z_H(1-z_L)^2}$

3.5 Comparative Statics

In this subsection, we derive propositions about the impact of the skill level of middle-skilled agents (z_M) on the proportion of remote teams and the offshoring patterns in different urban contexts.

First of all, we check the situation when cross-border communication is non-prohibitive, that is when $h_I < \hat{h}(z_H, z_L)$, and the urban area is congested enough in a sense that $\tau > \Phi(\frac{1}{2}; h_I, \gamma_T h_T)/H$. We define the ratio of remote teams as H_T/H, which is derived in E_{NT} as

$$\frac{H_T}{H} = \frac{H - H_N}{H} = 1 - \frac{\Phi(z_M; h_I, \gamma_T h_T)}{\tau H} \tag{3-140}$$

Thus, we further have

$$\frac{\partial(H_T/H)}{\partial z_M} = -\frac{\partial\Phi(z_M; h_I, \gamma_T h_T)/\partial z_M}{\tau H} \tag{3-141}$$

Given the equation (3-91), we have function Φ is concave, and for $z_M \in (\hat{z}_M(\gamma_T h_T), 1/2)$, $\partial\Phi(z_M; h_I, \gamma_T h_T)/\partial z_M > 0$, for $z_M \in (1/2, z_H)$, $\partial\Phi(z_M; h_I, \gamma_T h_T)/\partial z_M < 0$.

Therefore, H_T/H is convex, declines firstly until $z_M = 1/2$, then increases along with z_M closed to z_H (see Figure 3.11).

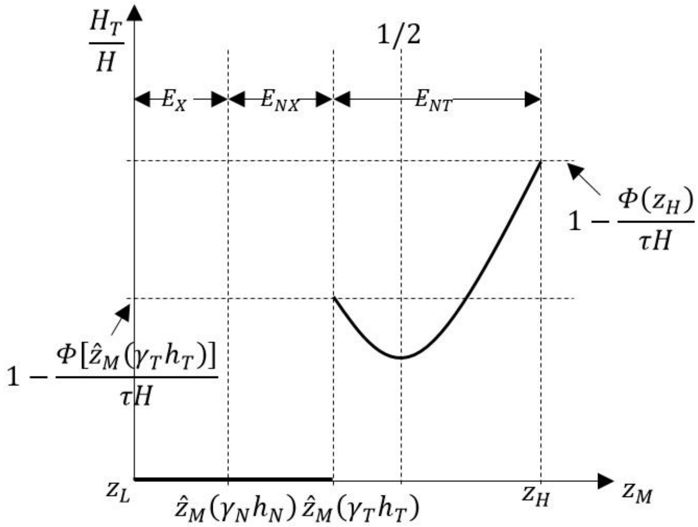

Figure 3.11: Impact of z_M on H_T/H when $h_I < \hat{h}(z_H, z_L)$ and $\tau > \Phi(\frac{1}{2}; h_I, \gamma_T h_T)/H$

Then, we check the situation when the urban area is less congested than the situation we discussed above, but is still quite congested in a sense that $\Phi(\hat{z}_M(\gamma_T h_T); h_I, \gamma_T h_T)/H < \tau < \Phi(\frac{1}{2}; h_I, \gamma_T h_T)/H$. We take the arithmetic average of τ, $\bar{\tau}$ as the representative level to draw figure, where

$$\bar{\tau} \equiv \frac{\Phi(\hat{z}_M(\gamma_T h_T); h_I, \gamma_T h_T) + \Phi(\frac{1}{2}; h_I, \gamma_T h_T)}{2H} \tag{3-142}$$

As the concavity of function Φ, the equilibrium offshoring pattern is E_{NT} firstly, then becomes E_N after across $\Phi_1^{-1}(\bar{\tau}H)$, them return to E_{NT} after across $\Phi_2^{-1}(\bar{\tau}H)$, where $\Phi_1^{-1}(\bar{\tau}H)$ and $\Phi_2^{-1}(\bar{\tau}H)$ are two real roots of equation $\Phi(z_M) = \bar{\tau}H$ (see Figure 3.12).

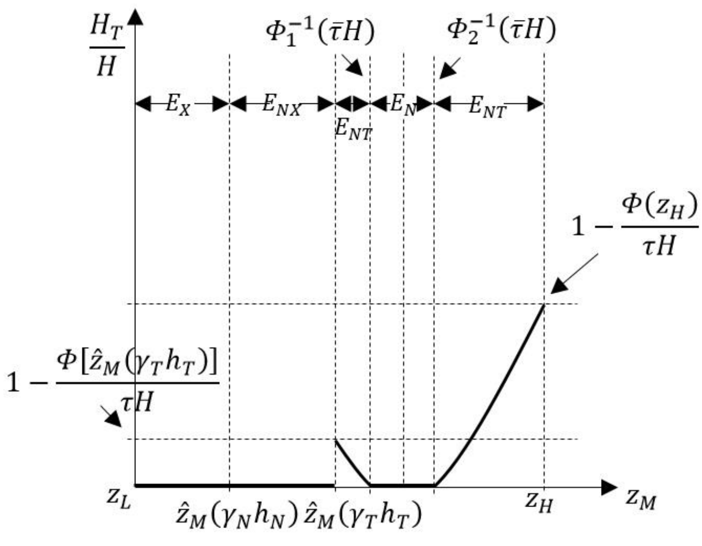

Figure 3.12: Impact of z_M on H_T/H when $h_I < \hat{h}(z_H, z_L)$ and $\tau = \bar{\tau}$

Then, we check the situation when the urban area is congested in medium level, meanwhile the improved telecommunication efficiency is not that much in a sense that $\Phi(z_H; h_I, \gamma_T h_T)/H < \tau < \Phi(\hat{z}_M(\gamma_T h_T); h_I, \gamma_T h_T)/H$ and $(z_H - z_L)(1-2z_L)/[(1-z_L)^2] < \gamma_T h_T < (z_H - z_L)^2/[z_H(1-z_L)^2]$. Similarly, we take the arithmetic average of τ, $\tilde{\tau}$ as the representative level to draw figure, where

$$\tilde{\tau} \equiv \frac{\Phi(z_H; h_I, \gamma_T h_T) + \Phi(\hat{z}_M(\gamma_T h_T); h_I, \gamma_T h_T)}{2H} \tag{3-143}$$

As $\gamma_T h_T$ is in medium level, $\hat{z}_M(\gamma_T h_T) > 1/2$, equilibrium offshoring pattern turns to E_N after across $\Psi_1^{-1}(\tilde{\tau}H)$, then turns to E_{NT} after across $\Phi_2^{-1}(\tilde{\tau}H)$, where $\Psi_1^{-1}(\tilde{\tau}H)$ is the smaller one of two real roots of equation $\Psi(z_M) = \tilde{\tau}H$ and $\Phi_2^{-1}(\tilde{\tau}H)$ is the larger one of two real roots of equation $\Phi(z_M) = \tilde{\tau}H$ (see Figure 3.13).

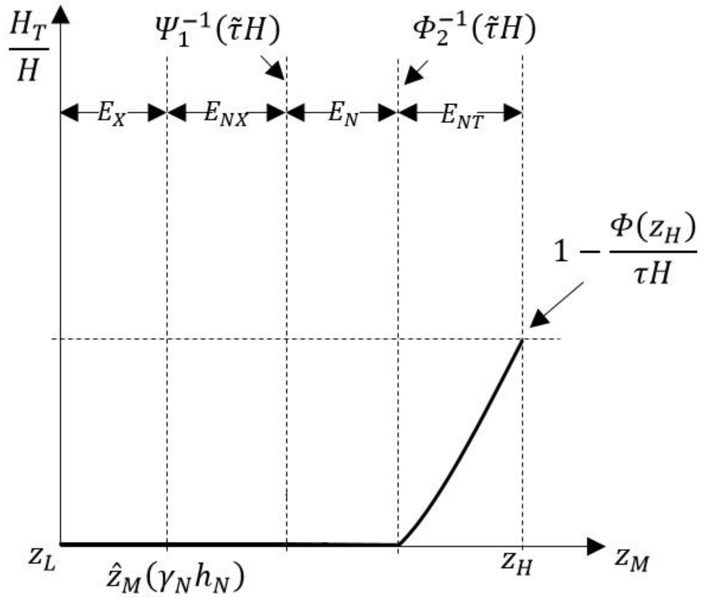

Figure 3.13: Impact of z_M on H_T/H when $h_I < \hat{h}(z_H, z_L)$ and $\tau = \tilde{\tau}$

The results above are concluded in the Proposition 3.5.1:

Proposition 3.5.1 *We identify three different patterns that the skill level of middle-skilled agents z_M affects the proportion of remote teams, along with the increase of z_M:*

(1) E_X-E_{NX}-E_{NT} pattern: there is an singular point over which a sudden boom is experienced in the growth rate of remote teams, then we witness a mild setback, finally it rebounds back to a level limited by the skill level of high-skilled agents z_H;

(2) E_X-E_{NX}-E_{NT}-E_N-E_{NT} pattern: there is an singular point over which a sudden boom is experienced in the growth rate of remote teams, then we witness a severe setback, the remote

teams totally disappear for a while, finally it rebounds back a level limited by the skill level of high-skilled agents z_H;

(3) E_X-E_{NX}-E_N-E_{NT} pattern: Neither singular point nor setback exists as the above two patterns, the proportion of remote teams grows slowly, but steadily to a level limited by the skill level of high-skilled agents z_H.

3.6 Concluding Remarks

Teleworking occurs worldwide, in developed countries as well in developing countries. In this Chapter, we build a model where multinationals decide whether organizing traditional team or remote team in host country. To organize a (local) remote team, local communication efficiency between local agents is compromised such that the "shield", which is composed of middle-skilled labor (but high-skilled labor if we limit our measure to the local level), must be thickened, meanwhile expenditure on office rental costs and commuting costs for employees are saved. This trade-off is balanced in equilibrium in a sense that no firms benefit from deviating from current organizational form.

We also highlight the role of middle-skilled labor, the skill level of them is crucial in determining the equilibrium offshoring pattern. To our best knowledge, we are the first to argue this point. Specifically, if we put it in a dynamic process in which the skill or knowledge level of local elites accumulates and grows in host countries[17], we will witness a boom, then a setback and finally a revival of proportion of remote workforce in metropolitan area.

There are still many issues to be discussed in the future. First of all, policy implication is one most important direction to be discussed further, although we derived six equilibrium offshoring patterns, we have adopted an ad hoc criterion in which we assume that government's unique objective is to increase the proportion of remote teams (H_T/H) because of reasons out of considerations in our model. This is hardly to be satisfactory.

[17]For example in China, the government has been ambitious on promoting the proportion of population whose degree are at least bachelor. In 1999, there were only 0.85 million of graduates from university, but in 2017, there were 7.95 million of graduates from university in single year, which is nearly 10 times than two decades ago. Although the number is growing dramatically, in 2017 only 4% of population who at least obtained the bachelor degree in China, and only 13% of 21 years' old population who're finishing their degrees.

3.7 Appendix

Proof of Lemma 3.4.4. We prove the Lemma 3.4.4 by contradiction. We presume that

$$\gamma_T h_T > \frac{(z_H - z_L)^2}{z_H(1 - z_L)^2} \tag{3-144}$$

which is equivalent to say

$$z_H < \hat{z}_M(\gamma_T h_T) \tag{3-145}$$

where

$$\hat{z}_M(\gamma_T h_T) \equiv \frac{(z_H - z_L)z_L}{z_H - z_L - \gamma_T h_T(1 - z_L)^2} \tag{3-146}$$

as

$$\begin{aligned} z_H < \frac{(z_H - z_L)z_L}{z_H - z_L - \gamma_T h_T(1 - z_L)^2} \quad &\Leftrightarrow \quad \gamma_T h_T z_H(1 - z_L)^2 > (z_H - z_L)^2 \\ &\Leftrightarrow \quad \gamma_T h_T > \frac{(z_H - z_L)^2}{z_H(1 - z_L)^2} \end{aligned} \tag{3-147}$$

as we have $z_M < z_H$ by definition, we thus have $z_M < \hat{z}_M(\gamma_T h_T)$, which is equivalent to say that the strategy T is dominated by the strategy X, that contradicts to the known: the strategy T dominates the strategy X.

Chapter 4

Estimates of Productivity Gap and Elasticity of Substitution between Teleworking and Office Working

4.1 Introduction

Traditional empirical research problems[1] in this field mainly focus on two issues:

1. Does teleworking promote dispersion of urban space?

2. Does teleworking substitute for household travel (commuting or non-commuting urban travel)?

Roughly 50% of all reviewed articles investigated teleworking, with much less on other tele-activities (e.g. teleshopping, teleservices, teleleisure). The main problems typical for all studies are related to (1) lack of universal definition; (2) small-scale data[2]; (3) lack of the theoretical models (Andreev, ti al., 2010).

[1]However, in terms of methodology, these studies mainly adopted a quasi-experimental approach using panel data from a few pilot projects with small sample sizes and limited study areas, thus limiting the generalizability of their findings. Under these circumstances, several researchers have emphasized the need for empirical approaches using large nationwide random samples (Salomon, 1986; Mokhtarian, 1998; Helling and Mokhtarian, 2001; Zhu, 2012; Kim et al, 2015). Datasets on teleworking can be categorized primarily as either small but detailed datasets from pilot teleworking studies in a specific area for usually a single employer, or datasets from large surveys of time use/travel behavior nationwide across many employers, many sectors. Many of the earlier studies are limited to data from a single employer or, at most, two or three employers.

[2]To summarize, the empirical studies of telecommuting mainly rely on two kinds of distinctive data sources and the corresponding methodologies they applied: quasi-experiments based on few pilot projects or multivariate regression approaches using large-scale travel/time use survey data.

In this chapter, we use a large-scale data of 2006 Survey on Time Use and Leisure Activities conducted by Statistics Bureau of Japan and adopt the approach proposed by De Graaff and Rietveld (2007) to estimate productivity gap and elasticity of substitution between office working and teleworking in Japan. As Andreev, ti al. (2010) mentioned, large-scale time use survey data and with sound theoretical models will help make up the problems for early studies. We review literature using large-scale travel/time use survey data as well since 2000s in the following firstly.

Related literature using large-scale time/travel use survey data. De Graaff and Rietveld (2004a) underlines the importance of timing issue: within conventional 9-to-5 working hours, possession of ICT facilities at home stimulates both at-home and at-office labor supply, relation between working time at office and at home is more a complement; outside 9-to-5 working hours, the time worked less at office is partly substituted by work at home. They also argue because 9-to-5 takes up the majority of labor supply, working time at office and at home is more a complement than substitute. De Graaff (2004) feels safe to say that the possibility of teleworking will cause a reduction in commuting, especially during the (morning) peak hours, and thus teleworking and commuting are more a substitute, partial effect: -0.092(0.013). De Graaff and Rietveld (2004b) argues that (Netherlands) workers have an intrinsic preference to work at home approximately 2.5 days a week. In the long run, their empirical results show that workers earn a 6% higher wage rate for every hour they commute per day. De Graaff and Rietveld (2007) argues that working at home leads to a reduction of the wage rate of about 19%, but this gap largely disappears when ICT is used for at-home work, meanwhile individual characteristics - age and education - seem to be more important for the choice between working at home and at office than ICT availability or commuting time. SN Kim, et al. (2015) uses 2006 Household Travel Survey in Korea, Seoul Metropolitan Area (SMA HTS) and shows that non-commute trips of teleworkers and his/her household members are greater than non-commute trips of non-teleworkers and his/her household members, they further show this difference is significant only in households with less than one vehicle per employed member. SN Kim (2016) estimates the usual compensatory travel to be around PKT of 2km.

The dataset De Graaff and Rietveld used for these series of studies called Dutch Time Use Survey (DTUS), two waves including 3,227 samples in 1995 and 1,813 samples in 2000, the sample size is much smaller than ours (we have 272,861 samples in 2006). During a week diary of each activity was recorded for each quarter of an hour (15 minutes), amongst others activities include working (location is given), shopping, traveling (for different purposes and using different modes), leisure and sleeping, in addition to activities, background characteristics (demographic, educational, work-related information, etc.) were also given. Compared to our dataset, their dataset is more like a panel data in a sense they include a week's observations of one individual, in our case we just have two consecutive days' observations. Besides, they have location information (it's very important to testify theoretical propositions) but we only know whether the subject lives at the three Metropolitan Areas in Japan. These limits in our dataset partially limit our ability to explore this issue.

Related literature estimating productivity gap. Bloom, et al. (2015) adopts an experiment based approach, their results show that home working leads to 13% performance increase, of which 9% is from working more minutes and 4% from more calls per minute (attributed to a quieter and more convenient working environment). Dutcher (2012) shows that working at home has positive implications on productivity of creative tasks but negative implications on productivity of dull tasks. Dutcher and Saral (2012) shows that belief on productivity of working at home, rather than the real productivity of working at home, determines productivity of teams including teleworking members. Mas and Moretti (2009) uses high-frequency data on worker productivity from a large supermarket chain. They find that worker effort is positively related to the productivity of workers who see him, but not workers who don't see him, and thus they conclude that social pressure can partially internalize free-riding externalities that are built into many workplaces.

We mainly explore two issues in this chapter: (1) firstly, we estimate the elasticity of substitution between office working and teleworking in Japan, although we don't emphasize substitution between commuting and teleworking, as we presume in our model to be estimated that office working is always accompanied by commuting behavior, this focus could be attributed to the second issue that the traditional empirical literature in this field focuses on; (2) secondly, we adopt the approach in Graaff and Rietveld (2007) to estimate the productivity gap between office working and teleworking in Japan.

As the results, we found that (1) the productivity of teleworking is 11-13% lower than office working in average (estimators are statistically significant in at least 0.05 confidence level) when we use different indicators of the availability of ICT appliances; (2) the productivity loss from teleworking is nearly fully recovered (from 13% loss recover back to 1% loss) if the subject workers own PC; but the mobile phone, as another ICT appliance, plays no role in the working productivity issue; (3) working at home and at office act as a less than perfect substitute, conditional on individual characteristics.

The remainder of the chapter contains six sections. Section 4.2 introduces the theoretical model; Section 4.3 introduces the empirical models to be estimated; Section 4.4 gives the basic data description and statistics summary; Section 4.5 reports the results of estimation and Section 4.6 makes the concluding remarks.

4.2 Theoretical Model

4.2.1 Demand System for Office Working and Teleworking

Firstly, we assume that there is an individual i, who wants to maximize his utility $U_i(C_i, h_{o,i}, h_{a,i}, l_i)$, with two constraints, the temporal constraint and the monetary constraint.

Temporal Constraint and Monetary Constraint . In terms of the temporal constraint, each individual is endowed with T_i units of time. She allocates her time endowment on different activities. We assume there are four kinds of activities, leisure, work, commuting and other supporting activities. We subdivide the work activities to two sub-activities, the work at office and the work out of office (mostly at home).

$$h_i \equiv h_{o,i} + h_{a,i} \tag{4-1}$$

where $h_{o,i}$ denotes the working time at office, and $h_{a,i}$ denotes the working time out of office. Then, we further assume that the time allocated to commute is positively proportional to the working time at office[3].

$$m_i = \theta h_{o,i} \tag{4-2}$$

where m_i denotes the commuting time.

This holds (somehow) in De Graaff and Rietveld (2007) as their samples are over a whole week (at most five workdays are counted), in our case we adopt two approaches to estimate

[3]Strictly speaking, it's the commuting frequency that is proportional to the office working frequency, and normally it will be twice as commuting is normally round trip. Here, θ essentially implies the (average) commuting time *burden* per unit of office working time, for example, Mr.A spends 2 hours in commuting (one-way commuting trip spends him 1 hour), and he works 8 hours at office, then θ_A is derived as 0.25, in another case Ms.B spends 3 hours in commuting and she works 8 hours as well at office, then θ_B is derived as 0.375. The fact that $\theta_A < \theta_B$ means that the efficiency of the usage of commuting of Mr.A is higher than Ms.B: in order to work at office for an hour, only 0.25 hours of commuting is required.

θ instead: approach (1) $\theta \equiv \theta_i = (\theta_i^1 + \theta_i^2)/2$, we treat θ as an individual dependent variable, which implies the (average) efficiency of the usage of commuting over two consecutive days: the lower the θ is, the more efficient the commuting is, in another word at-office working is cheaper and becomes more attractive for the individual i; approach (2) $\theta = \Sigma_i \theta_i / N$, where N denotes the sample size, this approach might be more likely the approach proposed by Graaff and Rietveld (2007). We will discuss in detail about how to derive θ in the next.

Finally, the temporal constraint of individual i is given by

$$\overline{T} = h_i + m_i + l_i + o_i \tag{4-3}$$

substitute (4-1) and (4-2) into it we derive

$$\overline{T} = (1+\theta)h_{o,i} + h_{a,i} + l_i + o_i \tag{4-4}$$

where l_i denotes the leisure time, and o_i denotes other supporting activities (e.g. sleep). To work 1 unit time at office, it uses $1+\theta$ units time endowment. In another word, θ measures the time lost due to commuting to work, and $\overline{T}$ is individual i's total time endowment over two consecutive days (namely, 48 hours).

We could also define $T_i \equiv \overline{T} - o_i$ as the *effective* time endowment over two consecutive days in a sense that T_i is exclusively allocated to activities directly (leisure) or indirectly (working at office or at home) increasing utility level:

$$T_i = (1+\theta)h_{o,i} + h_{a,i} + l_i \tag{4-5}$$

In terms of the monetary constraint, each individual spends all wage income on consumption (there is no saving at all and no non-labor income exists), which yields

$$W_i = C_i \tag{4-6}$$

where W_i denotes the wage income, and C_i denotes the consumption level.

Moreover, as the individual i works at office for $h_{o,i}$ hours and out of office (mostly at home) for $h_{a,i}$ hours, so that W_i is decomposed as

$$W_i = \omega_{o,i}h_{o,i} + \omega_{a,i}h_{a,i} \tag{4-7}$$

where $\omega_{o,i}$ and $\omega_{a,i}$ are *implicit* wage rates for working at office and out of office (mostly at home), respectively. Furthermore, we relate two wage rates to each other like the follows

$$\omega_{a,i} = \varphi(\xi_i)\omega_{o,i} \tag{4-8}$$

where ξ_i is an indicator variable which measures the availability of ICT appliances for individual i, and $1 - \varphi(\xi_i)$ represents the potential wage differential due to different locations to work like the follows

$$\frac{\omega_{o,i} - \omega_{a,i}}{\omega_{o,i}} = 1 - \varphi(\xi_i) \tag{4-9}$$

we will specify the function $\varphi(\xi_i)$ and discuss it in details in the next subsection.

Finally, the monetary constraint of individual i is given by

$$\omega_{o,i}[\varphi(\xi_i)h_{a,i} + h_{o,i}] = C_i \tag{4-10}$$

In combination of temporal and monetary constraints (4-5) and (4-10)[4], we derive the full budget constraint:

$$C_i + \omega_{o,i}[1 - \varphi(\xi_i)]h_{a,i} + \omega_{o,i}\theta h_{o,i} + \omega_{o,i}l_i = \omega_{o,i}T_i \tag{4-11}$$

where the implicit price of teleworking is $\omega_{o,i}[1-\varphi(\xi_i)]$, of office working is $w_{i,o}\theta$, and of leisure and other supporting activities is $\omega_{o,i}$.

In words, each activity is with a cost in a sense it takes up the time endowment which is used to earn wage income. Specifically, the office working is with a cost as it's accompanied by commuting behavior, which consumes the time endowment; the teleworking is with a cost as it might compromise (if $\varphi(\xi_i) < 1$, the price will be positive) the efficiency in usage of the time endowment; leisure and other supporting activities are with a cost as they consumes the time endowment directly.

Indirect Utility Function . With respect to the full budget constraint (4-11), individual i maximizes her utility function U_i:

$$U_i(C_i, h_{a,i}, h_{o,i}, l_i) \tag{4-12}$$

[4]Rewrite (4-5) to $h_{o,i} + h_{a,i} = T_i - \theta h_{o,i} - l_i$, then substitute it to (4-10).

Suppose C_i^*, $h_{a,i}^*$, $h_{o,i}^*$ and l_i^* as the Marshall demand functions for each activity given the implicit prices and the time endowment, we derive the indirect utility function V_i as follows:

$$V_i(p_C, \omega_{o,i}[1-\varphi(\xi_i)], w_{o,i}\theta, \omega_{o,i}; \omega_{o,i}T_i) \equiv U_i(C_i^*, h_{a,i}^*, h_{o,i}^*, l_i^*) \tag{4-13}$$

where p_C is the price of consumption (which we normalize at one), $\omega_{o,i}[1-\varphi(\xi_i)]$ and $w_{o,i}\theta$ are the price of working at home and at office, respectively, $w_{i,o}$ is the price of leisure (evaluated as the opportunity cost of time) and $\omega_{o,i}T_i$ the full income of individual i.

Transcendental logarithmic model (translog model) is one of the most popular, flexible and reliable specification in empirical work (Greene, 2008), which is often interpreted as a Taylor-Series approximation to an unknown functional form. The translog indirect utility function is normally specified as (Christensen, et al., 1975):

$$\ln(V) \approx \gamma_0 + \sum_{j=1}^{n} \gamma_j \ln(\frac{p_j}{Y}) + \frac{1}{2}\sum_{j=1}^{n}\sum_{k=1}^{n} \gamma_{jk} \ln(\frac{p_j}{Y})\ln(\frac{p_k}{Y}) \tag{4-14}$$

with goods/activities $j, k = \{C, h_a, h_o, l\}$ and their respective prices as in (4-13).

Budget Share Equation . We determine the budget share for the jth activities from the logarithmic form of the Roy's identity:

$$s_j \equiv \frac{p_j x_j}{Y} = -\frac{\frac{\partial \ln V}{\partial \ln p_j}}{\frac{\partial \ln V}{\partial \ln Y}} \tag{4-15}$$

where budget share of activity j is defined as the percentage of an individual's full income (Y) spent on activity j (e.g. working at home, working at office and leisure).

With the specification in terms of the indirect utility function by the equation (4-14), we have

$$\frac{\partial \ln V}{\partial \ln p_j} = \gamma_j + \sum_{k=1}^{n} \gamma_{jk} \ln(\frac{p_k}{Y}) \tag{4-16}$$

and

$$-\frac{\partial \ln V}{\partial \ln Y} = \sum_{j=1}^{n} \gamma_j + \sum_{j=1}^{n}\sum_{k=1}^{n} \gamma_{jk} \ln(\frac{p_k}{Y}) \tag{4-17}$$

hence, we have immediately

$$s_j = \frac{\gamma_j + \sum_{k=1}^{n} \gamma_{jk} \ln(\frac{p_k}{Y})}{\sum_{j=1}^{n} \gamma_j + \sum_{j=1}^{n}\sum_{k=1}^{n} \gamma_{jk} \ln(\frac{p_k}{Y})} \tag{4-18}$$

Since the budget share equations are homogenous of degree zero in the parameters (the γ's): (1) firstly a normalization of the parameters is required for estimation, we follow De Graaff and Rietveld (2007) to presume that

$$\sum_{j=1}^{n} \gamma_j = 1 \tag{4-19}$$

(2) secondly, we assume that U_i (or V_i) is homothetic, as the translog approximation to the homothetic utility function is not necessarily homothetic, a necessary and sufficient condition for homotheticity of the translog utility function is that it is homogenous, which requires

$$\sum_{j=1}^{n} \gamma_{jk} = 0 \tag{4-20}$$

Therefore, the budget share equation for the jth activity is derived by

$$s_j = \gamma_j + \sum_{k=1}^{n} \gamma_{jk} \ln(\frac{p_k}{Y}) \tag{4-21}$$

where γ_j can be treated as individual taste parameter for a specific activity j, and γ_{jk} as interaction parameter: how price of activity k increases affect the demand share of activity j.

Estimators of (4-21) now can be used to find price and substitution elasticities. There're three steps to derive Morishima elasticities of substitution (MES), which is more informative than the usually used Allen-Uzawa elasticities of substitution (AES):

1. Step 1: Calculate Allen-Uzawa elasticities of substitution with the translog specification (Allen, 1962):

$$\varsigma_{jj} = \frac{\gamma_{jj} + s_j^2 - s_j}{s_j^2} \tag{4-22}$$

$$\varsigma_{jk} = \frac{\gamma_{jk} + s_j s_k}{s_j s_k} \tag{4-23}$$

2. Step 2: Calculate price elasticities (Allen, 1938):

$$\varepsilon_{jj} \equiv \frac{\partial \ln x_j}{\partial \ln p_j} = \varsigma_{jj} s_j = \frac{\gamma_{jj}}{s_j} + s_j - 1 \tag{4-24}$$

$$\varepsilon_{jk} \equiv \frac{\partial \ln x_j}{\partial \ln p_k} = \varsigma_{jk} s_k = \frac{\gamma_{jk}}{s_j} + s_k \tag{4-25}$$

3. Step 3: Calculate Morishima elasticities of substitution:

$$v_{jk} = \varepsilon_{jk} - \varepsilon_{jj} \tag{4-26}$$

The MES can be interpreted as a measure of the ease of substitution and reflects the percentage change in relative shares induced by a percentage change in price ratios. Specifically,

$$\frac{\partial \ln (s_j/s_k)}{\partial \ln (p_j/p_k)} = 1 - v_{jk} \tag{4-27}$$

We will calculate them at s_j and s_k's means level after estimation.

After all, the key is to estimate the constructed budget share equation (4-21) for each activity j. The next section will deal with the empirical specification of such a system.

4.2.2 Productivity Gap between Office Working and Teleworking

Individuals who work for the same position may not receive the same observed wage income, this heterogeneity is from many aspects, and could be attributed to simply productivity heterogeneity in theory.

In this subsection, we try to build an empirically predictable equation such that the productivity gap between office working and teleworking can be estimated.

There are many potential reasons for why workers are more or less *productive* at office than at home, for example, workers might be more productive (per unit of time) at office than at home as they're able to communicate face-to-face with their colleagues, or superiors, the problem they met at work could be solved more quickly; on the other hand, worker might be more productive (per unit of time) at home than at office as they're less likely to be interrupted by colleagues, or superiors. Just as a popular saying goes: "every coin has two sides".

We consider a representative sample i who works at office for $h_{o,i}$ hours and at home for $h_{a,i}$ hours, thus her wage income W_i is decomposed into

$$W_i = \omega_{o,i} h_{o,i} + \omega_{a,i} h_{a,i} \tag{4-28}$$

where $\omega_{o,i}$ and $\omega_{a,i}$ are *implicit* wage rates for office working and teleworking, respectively. Then, we relate two implicit wage rates to each other in general form like the follows:

$$\omega_{a,i} = \varphi(\xi_i)\omega_{o,i} \tag{4-29}$$

where we further assume that $\varphi(\xi_i)$ follows

$$\varphi(\xi_i) \equiv \alpha_0 + \alpha_1 \xi_i \tag{4-30}$$

where ξ_i is an indicator variable which measures the availability of the ICT appliances for individual i, if $\alpha_1 = 0$, there will be no partial effect of the availability of the ICT appliances on the productivity in teleworking time. We predict that $0 < \alpha_1 < 1$ as communication friction will be somehow inhibited if some ICT appliances are available, such as PC, mobile phone.

Furthermore, as the normal specification of $\omega_{o,i}$ depends log-linearly on a set of exogenous variables X_i, for example gender, age, education, work experience, sector of employment, etc., we have

$$\omega_{o,i} = \exp(X_i \beta) \tag{4-31}$$

and from equation (4-29) and (4-30), we have

$$\omega_{a,i} = (\alpha_0 + \alpha_1 \xi_i) \exp(X_i \beta) \tag{4-32}$$

then, in combination with equation (4-7) yields the following individual wage income equation:

$$W_i = [h_{o,i} + (\alpha_0 + \alpha_1 \xi_i) h_{a,i}] \exp(X_i \beta) \tag{4-33}$$

Essentially, $\alpha_0 + \alpha_1 \xi_i$ indicates the relative productivity of teleworking time: if $\alpha_0 + \alpha_1 \xi_i > 1$, there will be a productivity gain for teleworking time, and the productivity gain is measured by $\alpha_0 + \alpha_1 \xi_i - 1$; conversely if $\alpha_0 + \alpha_1 \xi_i < 1$, there will be a productivity loss for teleworking time, and the productivity loss is measured by $1 - \alpha_0 - \alpha_1 \xi_i$, we will give the estimated results of the α's in the next.

4.2.3 Summary

To summarize the theoretical part, we derive a budget share equation for activity j as (4-21) and wage income equation as (4-33). It turns out that we should estimate (4-33) and derive function $\varphi(\xi_i)$ firstly, namely to estimate the α's and the β's; then with (4-11) and (4-13) we're able to calculate the prices $\{p_{h_a}, p_{h_o}, p_l\}$ (especially p_{h_a} because it's given by $\omega_{o,i}[1-\varphi(\xi_i)]$), and thus to estimate (4-33), namely to estimate the γ's; and finally calculate Morishima elasticities of substitution as (4-26).

4.3 Empirical Model

In order to estimate the equation (4-21) empirically (after we estimate $\varphi(\xi_i)$), three empirical models are estimated and their estimated results will be compared to each other. First is the OLS model as the benchmark, second is the Seemingly Unrelated Regression (SUR) model in which we consider correlations of the error term of each share equation, third is the Multivariate Tobit model, in which we consider the time for office working and (especially) teleworking as left-censored data.

4.3.1 Seemingly Unrelated Regression (SUR) Model

We construct a system of seemingly unrelated regression (SUR) model. Notice that there're reasonable reasons that the error term of each single share equation correlates to each other[5], thus we we pursue to system estimation, rather than single equation estimation to improve the efficiency of estimation[6].

However, if we use share equations for all four commodities/activities (C, h_a, h_o, l), then the system is singular because the shares sum up to one (Greene, 1993). Hence, we divide all prices by $p_C/Y = 1/Y$, essentially we drop the share equation for consumption (it's not relevant after all). Hence, the share equations (4-21) are now to be specified as follows:

Budget share for teleworking of individual $i = 1, \ldots, N$:

$$s_{h_a,i} = Z_i\delta_{h_a} + \gamma_{h_a h_a} \ln p_{h_a,i} + \gamma_{h_a h_o} \ln p_{h_o,i} + \gamma_{h_a l} \ln p_{l,i} + \varepsilon_{h_a,i} \tag{4-34}$$

Budget share for office working of individual $i = 1, \ldots, N$:

$$s_{h_o,i} = Z_i\delta_{h_o} + \gamma_{h_o h_a} \ln p_{h_a,i} + \gamma_{h_o h_o} \ln p_{h_o,i} + \gamma_{h_o l} \ln p_{l,i} + \varepsilon_{h_o,i} \tag{4-35}$$

[5]Because all the equations (4-21) are derived from the same utility maximization procedure, the unobserved personal characteristics variables will get into all error terms simultaneously, it's unlikely that the disturbances of the respective equations are independent to each other.

[6]When the error terms are correlated, the OLS estimators are still unbiased but the SUR estimators are more efficient (Greene, 2008).

Budget share for leisure of individual $i = 1, \ldots, N$:

$$s_{l,i} = Z_i\delta_l + \gamma_{lh_a} \ln p_{h_a,i} + \gamma_{lh_o} \ln p_{h_o,i} + \gamma_{ll} \ln p_{l,i} + \varepsilon_{l,i} \quad (4\text{-}36)$$

Notice $Z_i\delta_j$ where $j = h_o, h_a, l$ includes individual idiosyncratic characteristics such as age, gender, education, and other work-related variables.

4.3.2 Multivariate Tobit Model

However, the SUR estimator may not be unbiased either as the share of working time at office ($s_{h_o,i}$) and at home ($s_{h_a,i}$) take the value of zero in tremendous scale[7]. There're several reasons to be considered: (1) firstly, the sampling period may be too short to grasp the whole picture of the subject's working pattern, or (2) secondly due to the special occupational requirements.

Considering the share of working time at office ($s_{h_o,i}$) and at home ($s_{h_a,i}$) as left-censored data at zero removes this bias (De Graaff and Rietveld, 2007). We decide to use the Multivariate Tobit model, which is also called as the Seemingly Unrelated Censored Regression (SUCR) Model (Kim et al., 2015).

We thus rewrite the equations (4-34) to (4-36) as the following with the unobserved variables $s_i^* = (s_{h_a,i}^*, s_{h_o,i}^*, s_{l,i}^*)^T$ as the dependent variables:

Budget share for teleworking of individual $i = 1, \ldots, N$:

$$s_{h_a,i}^* = Z_i\delta_{h_a} + \gamma_{h_ah_a} \ln p_{h_a,i} + \gamma_{h_ah_o} \ln p_{h_o,i} + \gamma_{h_al} \ln p_{l,i} + \varepsilon_{h_a,i} \quad (4\text{-}37)$$

Budget share for office working of individual $i = 1, \ldots, N$:

$$s_{h_o,i}^* = Z_i\delta_{h_o} + \gamma_{h_oh_a} \ln p_{h_a,i} + \gamma_{h_oh_o} \ln p_{h_o,i} + \gamma_{h_ol} \ln p_{l,i} + \varepsilon_{h_o,i} \quad (4\text{-}38)$$

Budget share for leisure of individual $i = 1, \ldots, N$:

$$s_{l,i}^* = Z_i\delta_l + \gamma_{lh_a} \ln p_{h_a,i} + \gamma_{lh_o} \ln p_{h_o,i} + \gamma_{ll} \ln p_{l,i} + \varepsilon_{l,i} \quad (4\text{-}39)$$

The observed variables $s_{j,i}$ is related to the latent variable $s_{j,i}^*$ through the observation

[7] Compared to De Graaff and Rietveld (2007)'s one week sampling period, our dataset only offers two consecutive days' sample, thus we suffer more from zero-value problem of working time at office and at home.

rule:

$$s_{j,i} = \begin{cases} s^*_{j,i}, & if\ s^*_{j,i} > 0 \\ 0, & if\ s^*_{j,i} \le 0 \end{cases} \tag{4-40}$$

where $j = h_a, h_o$ and $s_{l,i} = s^*_{l,i}$, namely observations of office working and teleworking time are left-censored at zero, and observations of leisure are not censored.

4.4 Data Description and Statistics Summary

This study utilized anonymized questionaire information from the Survey on Time Use and Leisure Activities conducted by the Statistics Bureau of Japan, provided by the National Statistics Center through Kobe University Microdata Center (KUMiC) in 2017. The data shown in this chapter is the one processed by the author based on the original information and not identical to those provided by the Statistics Bureau of Japan.

The survey covers 55,484 households and 272,861 samples (roughly 5 members per household) in all 47 prefectures of Japan. The respondents are asked to report their time use on randomly selected two consecutive days from 14th to 22th, October in 2006, during which 20 kinds of activities (e.g. commuting, work, shopping, moving but excluding commuting, etc.) were recorded for each quarter of an hour, namely 15 minutes and thus there will be in total 192 activity records for each sample. Detailed information including the availability of ICT appliance, normal one-way commuting time (a proxy of commuting length), car ownership and basic demographic characteristics for each sample are also provided in this dataset.

4.4.1 Measurement Issues

Who is identified as teleworker? Unfortunately we don't have employment type information like in Kim (2016), in contrast to the case when the subject *claims* herself to be a teleworker as in Kim (2016)[8], we have to make our own operational definitions.

We mark the subject as narrowly defined teleworker when during the two consecutive days the subject (1) works from home *at least* one whole workday (Q24) and (2) whose *normal* one-way commuting time is larger than zero (Q15). Thus, a narrowly defined teleworker, based on our identification rule, will commute to work *normally* but "happen to" work from home

[8]In Kim (2016), the operational definition of a teleworker is a white-collar worker who chose "teleworker" from the four options of employment type (teleworker; full-time office worker; part-time office worker; and other).

at least one whole workday during the sampling period. In another word, we include part of identifiable occasional teleworkers (without employers' formal teleworking policy), partial teleworkers (with employers' formal teleworking policy), but exclude full-time teleworkers in our sample, only those samples exhibit *anomaly* in a sense that her normal commuting behavior contradicts to her commuting behavior during sampling period will be counted.

Who is identified as conventional/normal worker? On the other hand, we mark the subject as conventional/normal worker when during the two consecutive days the subject (1) commutes to work at all workdays (Q24) and (2) whose *normal* one-way commuting time is larger than zero (Q15). As based on our identification rule, there will be some occasional teleworkers and/or partial teleworkers who "happen to" commute to work at all workdays during the sampling period. We have no idea about how to pick them up. That's one limit of our dataset, and it may bring bias into our analysis.

Office working and teleworking time. To measure the productivity gap between office working and teleworking, we need to have information about office working and teleworking time, unfortunately as well, we have to make our own operational definition to derive them.

Follow De Graaff and Rietveld (2007), one operational approach to measure the productivity gap is that, we don't obsess about the definition of teleworker and normal worker[9], instead we consider that each worker's productivity will rely on a working time weighted sum of the working productivity at office and at home.

In another word, De Graaff and Rietveld (2007) avoids the tough problem of definition, but turn to think about there is a continuum in one extreme all working time is at office, and in another extreme all working time is at home, the individual productivity will be a function of the distribution of working time. Hence, they're not estimating the productivity gap between teleworker and normal worker, instead they are estimating the productivity gap between working time at office and at home. We will follow their approach.

See Figure 4.1, we identify five in total patterns to derive the working time at office and at home.

We have to drop many "uncommon" samples that beyond our interest: firstly, we won't include those samples in unusual days, like the day for travel or excursion (more than half a day), the day for wedding or funeral (lasting over half a day), the day for business trip or

[9]Because their dataset is similar with ours, no employment type information at all and thus any definition might bring bias into the analysis.

training, the day in hospital, and the day of holiday or vacation, this leaves us 192,203 samples; secondly, we won't include those samples in which the individual is not engaged in work at all, like those who're doing housework as housewife or househusband, those who're attending school, and other activities but not including works, this leaves us 101,791 samples; thirdly, to serve our specific interest, we will only include those samples in which the individual works as an employee, rather than other identities, like those who are self-employed, family worker, etc. This leaves us finally 71,705 effective samples.

In words, (1) Pattern 1: the subject engages in working but without commuting trips, as we normally presume that the subject won't sleep at office, thus it's safe to say that the subject is working outside the office, and mostly at home; (2) Pattern 2: the subject before and after working engages in commuting activities, thus we identify that the working activities occur at office; (3) Pattern 3, 4 and 5: these three patterns are essentially a mix of Pattern 1 and 2, as the common feature of these three patterns, the subject's working time is *fragmented*, rather than *integrated* as in Pattern 1 and 2: besides the working time between two commuting activities, the subject in Pattern 3 also engages in working *before* commuting to the office, the subject in Pattern 4 also engages in working *after* commuting back to the home, the subject in Pattern 5 also engages in working *before* and *after* commuting trips.

To conclude, only those working time between two period of commuting time is identified as the time for office working, those working time without commuting spell at all (in Pattern 1), or before the first commuting spell (in Pattern 3 and 5), or after the last commuting spell (in Pattern 4 and 5), will be identified as the time for teleworking.

Some of the samples are beyond these five patterns, because of several different reasons: (1) firstly, some samples only involve one single spell of commuting, rather than a pair of commuting spells, which is strange as normally commuting trips are daily round trips. After we check the "problem" samples in detail, we found although the trip to the office is normally correctly recorded as commuting, the return trip back to the home is usually "wrongly" recorded as shopping, sports, or moving excluding commuting activities; (2) secondly, no working spell at all; (3) thirdly, there're more than a pair of commuting spells.

The further reason may be twofold: (1) firstly, those subjects do *also* engage in these activities on the way home, for example in terms of sports, perhaps the subject, after work, stops in a nearby gym, does some exercises, then goes back home; (2) secondly, as what the subject fills in depends on how the subject perceives the activities in that period, even if two subjects do the same activities after work, their records might be different.

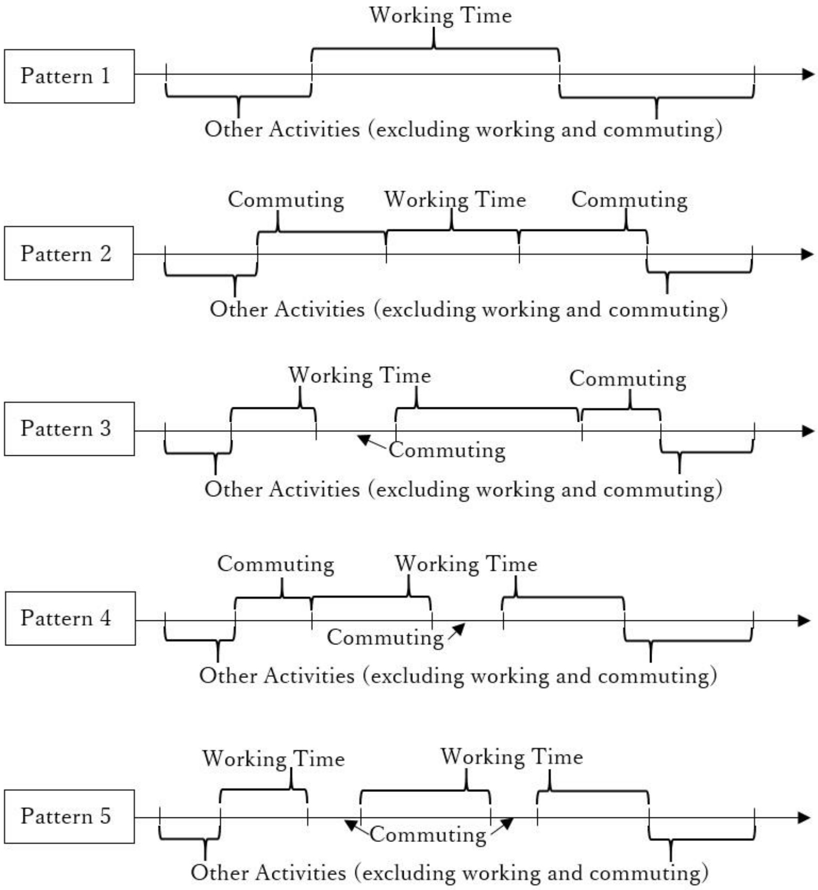

Figure 4.1: Sample Patterns

Should we include these samples whose patterns are beyond these five patterns? It depends actually, one difficulty to include them is because it's hard to identify the time for office working and teleworking. Hence, given our needs we decide to drop those samples whose patterns are beyond these five patterns.

Summary. The data doesn't tell us who are teleworkers, and who're not. Any operational definition will bring bias consequentially. However, it doesn't fail us to estimate the productivity gap between office working and teleworking time if we use the approach proposed by De Graaff and Rietveld (2007).

4.4.2 Statistical Characteristics

In this subsection, we firstly follow the *identification rule* we specified above, show the conditional means of the total time of working, the time of office working and teleworking, and the leisure time to give us a preliminary image about *who* works more at office, or at home;

then, secondly we explore the relation between the time for office working and teleworking. Basically, this part is a preparation stage for the multivariate regression analysis in the next section.

Conditional means of working time and leisure . In words to conclude (see Table 4.2 and 4.3): (1) The male works more hours (2.08 hours) than the female, the extra hours of working are mostly at office; (2) Workers at core region work more hours (0.1 hours) at office, meanwhile work less hours (0.38 hours) than workers at peripheral region; (3) More aged workers work less at office, work more at home, although the total working time declines with the age; (4) More educated workers work more at office, work less at home; (5) Workers with higher position in firms work more at office, work less at home; (6) Workers who commute longer work more at office, and less at home; (7) Workers who use ICT appliance (e.g. the mobile phone, PC) work more at office, work less at home; (8) Workers who burden nursing duties work less at office, work more at home.

Temporal distribution of daily working and commuting time. Figure 4.2 shows that in Japan (1) working time is highly concentrated on two intervals: 8-to-12 and 13-to-18 take up the majority of working time; (2) the right tail is thicker than the left tail, it implies that out-of-conventional working time is more biased towards conventional after-work time, than before-work time. Figure 4.3 shows that in Japan (1) commuting time is asymmetrically concentrated on 6-to-9 morning peak period; (2) among 17-to-20, commuting time is more evenly distributed, it reflects that tradition of overtime work of salary-man in Japan.

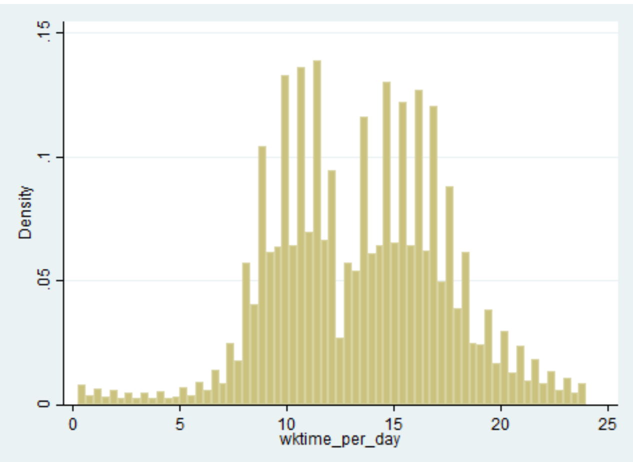

Figure 4.2: Temporal distribution of working time

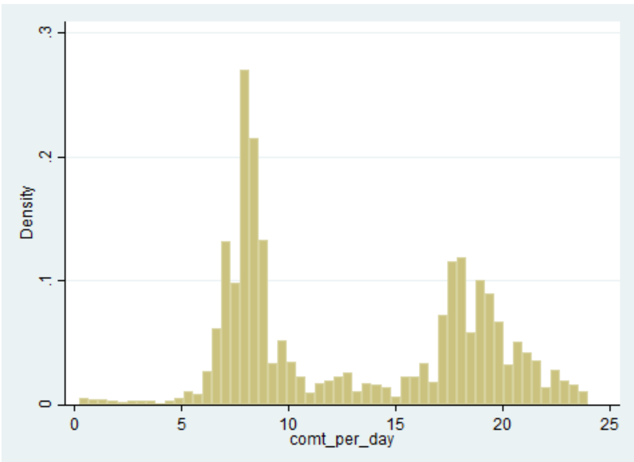

Figure 4.3: Temporal distribution of commuting time

Table 4.1: Conditional Means of Working Time and Leisure

	Time for Office Working	Time for Teleworking	Total Working Time	Leisure[1]
(1)				
Male	7.41	1.13	8.55	3.73
Female	5.35	1.12	6.47	3.80
(2)				
Core region	6.53	0.86	7.40	3.76
Peripheral region	6.43	1.24	7.67	3.79
(3)				
Age<30	7.08	1.02	8.10	3.79
Age 30-40	7.18	0.94	8.12	3.35
Age 40-50	6.86	1.03	7.89	3.55
Age 50-60	6.32	1.17	7.49	3.80
Age 60-70	4.48	1.47	5.96	4.65
Age>70	2.35	2.36	4.71	5.39
(4)				
Elementray school/ junior high school	5.40	1.64	7.04	4.17
High School	6.41	1.14	7.55	3.86
Junior college/ technological college	6.59	0.89	7.48	3.56
College/university, graduate school	6.41	1.14	7.55	3.86
(5)				
Managers and officials	7.92	0.98	8.90	3.77
Clerical and related workers	6.73	1.13	7.85	3.88
Sales workers	5.10	1.20	6.30	4.56

[1] Leisure is defined by the summation of time spent on shopping, watching the television, reading the newspaper or magazine, listen to the radio, sports and hobby, receiving or making visits and breaking during daytime.

Table 4.2: Conditional Means of Working Time and Leisure(con't)

	Time for Office Working	Time for Teleworking	Total Working Time	Leisure
(6)				
Commuting time (in general)				
Usually zero	0.24	4.41	4.65	5.00
0-15min	5.62	1.60	7.22	4.06
15-30min	7.07	0.74	7.81	3.77
30-45min	7.54	0.60	8.14	3.46
45-60min	7.56	0.56	8.12	3.34
(7)				
For whom uses mobile phone	6.73	1.05	7.77	3.71
For whom uses PC	7.09	0.86	7.95	3.64
For whom doesn't own any ICT appliance	4.72	1.64	6.37	4.26
(8)				
Nursing	5.38	1.38	6.76	3.71
No nursing	6.51	1.11	7.63	3.78

Figure 4.4 and Figure 4.5 show that in Japan (1) working time at home is more concentrated on the conventional working hours, as the working time distribution exhibits, of 8-to-12 and 13-to-18, which is a little surprising result as normally we believe that working time at home should be more flexible, but as we only include those samples working as employees (and excluding those self-employed or family home workers), an overlap with the conventional working hours becomes reasonable, it reflects time synchronization between working time at home and at office; (2) working at office is more evenly distributed compared to working time at home.

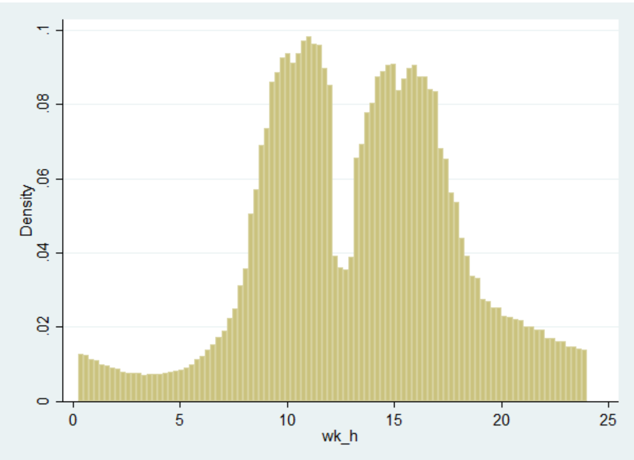

Figure 4.4: Temporal distribution of working time at home

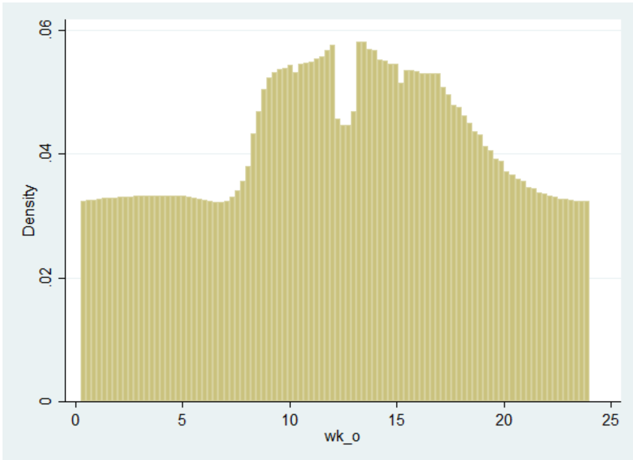

Figure 4.5: Temporal distribution of commuting time at office

Empirical relation between office working and teleworking time . Figure 4.6 shows that (1) there is a nearly one-to-one (-0.82) substitutional relation between office working time and teleworking time, in other words, whenever 1 unit of working hours at home is increased, 0.82 units of working hours at office are decreased; (2) samples that either only work at office or at home are the overwhelming majority; (3) samples who at least work some hours at office are the overwhelming majority; (4) samples are highly heterogeneous, which implies that personal characteristics, such as sector of employment, the number of children younger than 6 to bring up, alternative workplace except office, are most likely to play an important role in individual decision in time allocation between office working and teleworking, we construct a multivariate regression model in the next subsection.

Besides, Figure 4.7 shows that there is a (-0.46) substitutional relation between working time and leisure, in other words, whenever 1 unit of working hours is increased, 0.46 units of leisure are decreased.

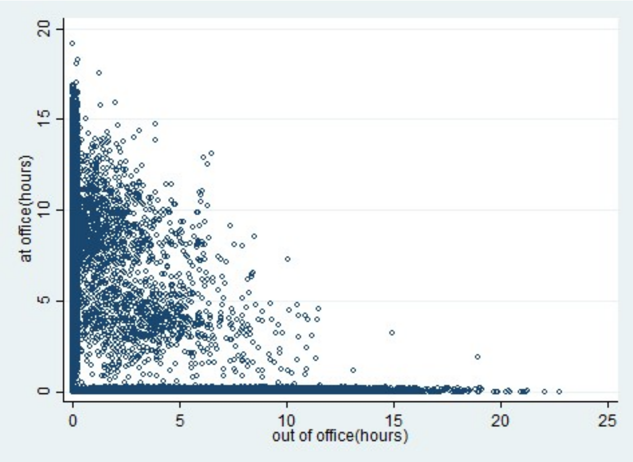

Figure 4.6: Office working time = 7.38 (.016) - 0.82 (.005) * Teleworking time

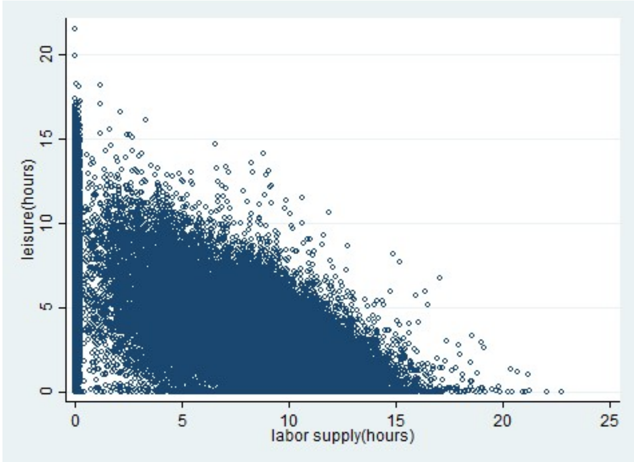

Figure 4.7: Leisure time = 7.30 (.020) - 0.46 (.002) * Total working time

4.5 Estimated Results

4.5.1 Estimates of the Productivity Gain (Loss) of Teleworking

In this subsection, we estimate equation (4-33) and derive the estimates of productivity gap between teleworking and office working. Specifically, in the equation (4-13) where $h_{o,i}$, $h_{a,i}$, ξ_i and X_i are the known, and we estimate parameters the α's and the β's using the Non-linear Least Square (NLS) regression method.

No prior knowledge about the sign of $1 - \varphi(\xi_i)$ is presumed. Working at office could be more productive or less productive than working at home. Specifically, working at office might be more productive if (1) they're less disturbed by family members; (2) some people my be hard to transit from family role to work role if working at home; on the other hand, working at home might be more productive if (1) they're less disturbed by colleagues at office; (2) firms themselves may save office rental cost when employees are working at home.

Unfortunately, the survey data only offers information about yearly *household* total wage income, which means that in multiple earner households individual incomes are not directly given.

Our strategy to tackle with this identification problem follows two steps: (1) we firstly sample those in which the respondent is working and single, or the respondent is the only working household member, this results 4,213 single and working observations, 6,071 observations in which the male respondent is the only working household member, and 1,163 observations in which the female respondent is the only working household member. In total, 11,203 observations of individual yearly wage incomes are derived, which enables us to estimate the equation (13); (2) then secondly, we impute wages on full samples. We report the estimated results in Table 4.3:

Specifically, in terms of the choice of ξ_i and X_i: (1) the control variables that determine the wage rate include gender, age, region, education and occupation[10]; (2) the usage of PC, and mobile phone are used to be the indicator variables to measure the availability of ICT appliance.

We found from the estimation results (see Table 4.3) that (1) the productivity of teleworking is 11%-13% lower than office working if there is no any ICT appliance, and it's statistically significant in 0.05 confidence level; (2) if mobile phone is available when teleworking, the productivity loss is complemented by 5%, such that the consequential productivity loss is suppressed to 6%. However, the partial effect of mobile phone is not statistically significant in 0.05 confidence level, hence it's less convincing to argue that the availability of mobile phone at home will play an important role in teleworking productivity issue; (3) if PC is available when teleworking, the productivity loss is complemented by 12%, such that the consequential productivity loss is suppressed to merely 1%, nearly completely cover the productivity loss. Meanwhile, the partial effect of PC is statistically significant in 0.05 confidence level, it implies that the availability of PC will drastically alleviate the productivity loss when teleworking.

The estimation that incorporates both indicator variables: PC and mobile phone, has been also implemented. The result is quite similar to the estimation where only the indicator variable PC is included: $\alpha_0 = 0.88(0.03)^*, \alpha_{ph} = 0.02(0.03)$ and $\alpha_{pc} = 0.12(0.03)^*$.

Compared to De Graaff and Rietveld (2007)'s estimation, they report a 19% productivity loss due to teleworking and the loss is not recovered even if Internet connection is available[11], the evidence for a significant effect of the presence of ICT is less convincing in their estimation. However, (probably) giving the credit to large sample size (our effective sample size is 10 times larger than theirs), our estimation offers more support on the significance of the presence of ICT appliance (PC in our case), with PC being available, the productivity is nearly fully recovered (<1% loss), which is a very encouraging result.

[10] Occupation is classified on the basis of the Occupational Classification for the Population Census.

[11] Specifically speaking, although $\alpha_0 = 0.81$ is statistically different form zero, $\alpha_1 = 0.16$ is not statistically significant.

Table 4.3: Nonlinear Least-squares (NLS) Estimates

Variables	Coef.(Robust Std. Err.)	
	PC	Mobile phone
Constant	-4.25(0.03)*	-4.25(0.03)*
Male dummy=1	0.02(0.01)	0.02(0.01)*
Age dummies (reference case=age>70)		
Age<30	-0.30(0.03)*	-0.30(0.03)*
Age(30-40)	-0.14(0.03)*	-0.14(0.03)*
Age(40-50)	-0.12(0.03)*	-0.12(0.03)*
Age(50-60)	-0.11(0.03)*	-0.11(0.03)*
Age(60-70)	-0.02(0.03)	-0.02(0.03)
Educational dummies(reference case=College/university, graduate school)		
Persons attending school or never attended school	-0.23(0.05)*	-0.20(0.05)*
Elementary school or junior high school	-0.08(0.02)*	-0.08(0.02)*
High school	0.04(0.01)*	0.03(0.01)*
Junior college or technological college	0.01(0.02)	0.01(0.02)
Occupational dummies(reference case=clerical and related workers)		
Professional and technical workers	-0.05(0.01)*	-0.06(0.01)*
Managers and officials	-0.1(0.04)*	-0.1(0.04)*
Sales workers	0.01(0.02)	0.002(0.02)
Protective service workers and service workers	-0.02(0.02)	-0.01(0.02)
Agricultural, forestry and fishery workers	-0.22(0.05)*	-0.22(0.05)*
Workers in transport and communicational occupation	0.05(0.01)*	0.05(0.01)*
Workers not classifiable by occupation	-0.13(0.02)*	-0.13(0.02)*
Structural parameters		
α_0	0.87(0.02)*	0.89(0.03)*
α_1	0.12(0.03)*	0.05(0.03)
Adj R^2	0.76	0.76
Root MSE	3.61	3.61
Number of Obs	11,203	11,181

[1] The * indicates coefficients that are significant at the $\alpha = 0.05$ level of higher.

4.5.2 Estimates of the Elasticity of Substitution between Office Working and Teleworking

With the estimation of $\varphi(\xi_i) \approx 0.87 + 0.12\xi_i$, we're able to specify an implicit price for working at home. To estimate (4-34) to (4-36) (or (4-37) to (4-39)), we need the shares (4-15) and the prices (4-13).

Firstly, the effective time endowment T_i is derived either summing up all quarters of hours spent over two consecutive days on working at home and at office, leisure and commuting, where leisure l_i is measured by the summation of all quarters of hours spent over two consecutive days on shopping (a10[12]), watching television, listening to the radio and news, reading the magazine (a12), resting (a13), interest and hobby (a15), sports (a16), volunteer activity and social practice activity (a17) and receiving or making visits (a19), working hours $h_{a,i}$ and $h_{o,i}$(see Figure 4.1 about how we derive working time at home and at office, see Figure 4.4 to 4.6 and Table 4.1 to derive more information about working time distribution) and commuting hours m_i are directly given.

Secondly, wage rate per unit time (at office as the benchmark) $\omega_{o,i}$ is derived as (4-31), then full income Y_i is then derived by $\omega_{o,i}T_i$,

Thirdly, we derive the prices. the price of individual i's leisure $p_{l,i}$ is directly equal to $\omega_{o,i}$, the price of working time at office (or for commuting) $p_{o,i}$ is derived as $(m_i/h_{o,i})\omega_{o,i}$ (see (4-2)), then the price of working time at home $p_{a,i}$ is given by $[1 - \varphi(\xi_i)]\omega_{o,i}$ (see (4-13)).

Finally, the share of leisure, working at office and at home are derived as $p_{l,i}l_i/Y_i$, $p_{o,i}h_{o,i}/Y_i$ and $p_{a,i}h_{a,i}/Y_i$, respectively.

Before we report the maximum likelihood estimated results, let's clarify more technical parts that either we speculate from existing literature, or we make our own rule to derive or estimate it because our Japanese dataset doesn't offer the same information as the dataset used in the reference literature.

More clarifications. Firstly, we clarify how θ_i (see (4-2)) is actually derived and why we have to do it in that way. One problem we met in our dataset is that for many individuals report a total zero commuting time (m_i) in two consecutive days, this gets us into trouble because $p_{o,i}$ is derived as $(m_i/h_{o,i})\omega_{o,i}$, and we evaluate the logarithm of it when we estimate the share equations (see (4-34) to (4-36)), zero price of working at office makes us obtain a negative infinity of value.

[12]Here a10 means the 10th activity in the activity list.

One approach is to drop all the samples with zero commuting time, but this approach will quite possibly just drop the samples that we're most concerned. The samples who work at home during that two consecutive days (that's way the commuting time is zero!) may firstly be a full-time teleworker, or secondly be a partial teleworker who normally commute to work, but just when we observe her, she works at home during that two consecutive days.

Hence, we decide to adopt the approach in the following. Q15 in our survey offers the information about how long the one-way commuting trips *normally* is for that individual, here *normally* implies that even if m_i is zero (such that we can not derive the price for working at office successfully), the answer to Q15 might not be zero. This seemingly inconsistency about the information of commuting actually implies that the sampled individual is a partial teleworker.

But if m_i is zero and simultaneously the answer to Q15 is zero as well. Although the sampled individual may probably be a full-time teleworker, we have to drop them because of the estimation system that we specified. Besides, if m_i is positive and simultaneously the answer to Q15 is positive as well, as two datas is positively correlated (if m_i is high, then the answer to Q15 is also high), we will use the answer to Q15 rather than m_i. See Figure 4.8, most of samples commute less than one hour for round trip.

On the other hand, the denominator of the estimated price for working at office, namely working hours at office, can be also zero partially because of the short sampling interval, as there is no substitute data, we have to drop them.

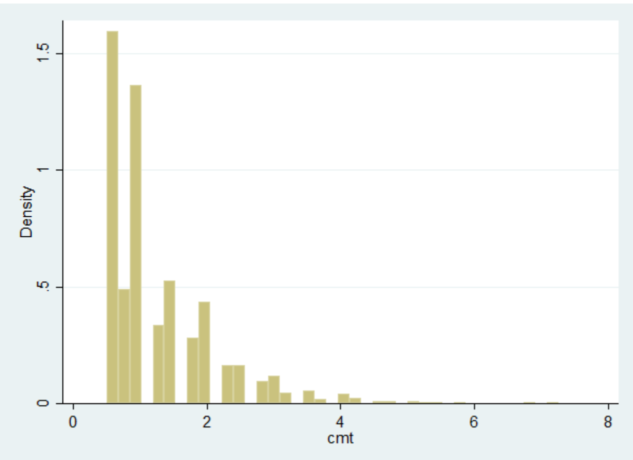

Figure 4.8: Distribution of the estimated commuting hours

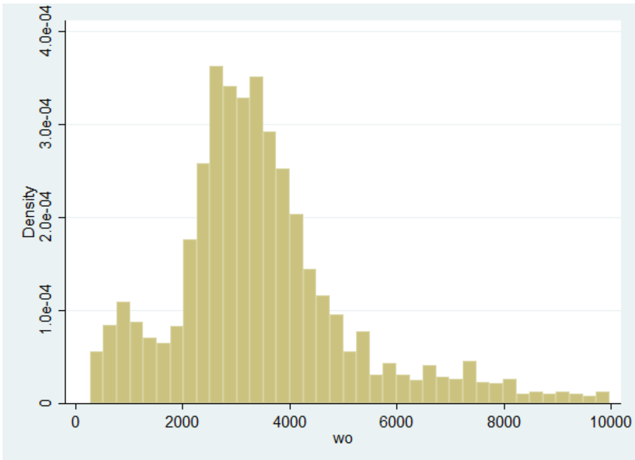

Figure 4.9: Distribution of the estimated hourly income

Secondly, we have yearly income but we need to use estimated result of (4-33) to derive hourly wage rate. We presume that one year includes 365 days, among which 113 days are legal holidays, and 9 days are holidays with pay, this leaves us 243 days for work days. For example, for 5,000,000 yen yearly income, the daily income is derived by 5,000,000/243, which gives 20,576 per work day, and if the total working hours is 8 hours, then we have 2,572 yen per hour. See Figure 4.9, the hourly wage rate is with mean 3,484 yen and median 3,220 yen.

We report the estimates in Table 4.4:

Almost all structural parameters in Table 4.4 are significant. However, because these parameters are direct estimates of censored regressions for both working at home and at office, direct interpretation is difficult. However, we can check the sign of dummies for the age, educational and occupational groups.

Firstly of all, being male tends to work more at office, less at home and enjoy less leisure. Then, younger individual tends to work more, and more at home, the individuals aged from 30-50 works more at office and all of them enjoy less leisure than the aged. Thirdly, the less educated individuals works less at home and at office, meanwhile own more leisure time. Finally, the sales workers work less at office, the individuals with transport and communicational occupation work more at office as well.

Finally, we calculate the substitution elasticity using the estimates in Table 4.4 (see Table 4.5). When Morishima elasticity is larger than one, activity j can be considered as a more than perfect substitute for activity k, if the elasticity is smaller than one, activity j is considered a less than perfect substitute for activity k (De Graaff and Rietveld, 2007). Hence, we clarify the results in Table 4.5 that working at home and at office act as a less than perfect substitute, conditional on individual characteristics.

4.6 Concluding Remarks

In this chapter we focus on estimating the productivity gap and substitution elasticity between working time at home and at office.

Using the Survey on Time use and Leisure Activities conducted by Statistics Bureau of Japan in 2006, which covers 55,484 households in all 47 prefectures of Japan. We found that (1) the productivity of working at home is 11-13% lower than office working in average when we use different indicators of the availability of ICT appliances (PC and mobile phone); (2) the productivity loss from working at home is nearly fully recovered if the subject workers own PC; mobile phone turns to play much less role in productivity issue, partially because our dataset is in 2006, right before the official release of the first generation of iPone on June

Table 4.4: Estimates For the Share Equations

Variables	Coef.		
	s_a(T)	s_o(T)	s_l(O)
Constant	**0.062**	**0.291**	-0.042
Male dummy=1	**-0.004**	**0.008**	**-0.031**
Age dummies (reference case=age>70)			
Age<30	**0.016**	**0.007**	**-0.054**
Age(30-40)	**0.013**	**0.008**	**-0.077**
Age(40-50)	**0.013**	**0.008**	**-0.066**
Age(50-60)	**0.014**	**0.005**	**-0.041**
Age(60-70)	**0.012**	**0.002**	-0.010
Educational dummies(reference case=College/university, graduate school)			
Persons attending school or never attended school	-0.007	**-0.007**	**0.056**
Elementary school or junior high school	0.001	**-0.005**	**0.029**
High school	-0.001	**-0.004**	**0.028**
Junior college or technological college	-0.001	**-0.002**	**0.015**
Occupational dummies(reference case=clerical and related workers)			
Professional and technical workers	0.003	0.002	**-0.016**
Sales workers	-0.002	**-0.004**	**0.036**
Protective service workers and service workers	0.001	**0.003**	**-0.017**
Agricultural, forestry and fishery workers	-0.002	**0.007**	**-0.020**
Transport and communicational occupation	0.001	**0.004**	**-0.012**
Workers not classifiable by occupation	0.001	-0.002	0.001
Structural parameters (Interaction parameters)			
$\gamma_{h_a h_a}$	**0.011**		
$\gamma_{h_a h_o}$	**0.004**		
$\gamma_{h_a l}$	**-0.017**		
$\gamma_{h_o h_a}$		**-0.001**	
$\gamma_{h_o h_o}$		**0.081**	
$\gamma_{h_o l}$		**-0.085**	
$\gamma_{l h_a}$			**0.003**
$\gamma_{l h_o}$			-0.004
γ_{ll}			**0.042**
Adj R^2	0.54	0.81	0.14
Number of Obs	7,962	7,962	7,962

[1] Bold=significant at 5%.

Table 4.5: Implied Morishima Elasticities of Substitution

	Working at home	Working at office	Leisure
At home	1.000	0.797	0.771
At office	0.595	1.000	0.900
Leisure	1.415	1.125	1.000

29, 2007; (3) working at home and at office act as a less than perfect substitute (0.797<1), conditional on individual characteristics.

Our dataset is quite limited in a sense that we only have two consecutive days (most of time it even includes Saturday or Sunday), this makes the period interval in which the subject optimizes time allocation on activities becomes too short, such that the subject are in no way *really* optimizing their time allocations[13]. Besides, the dataset gives no clue about who claims theirselves as teleworker, partially or full-time, any arbitrary definition will bring biases that might affect the estimates, the implication is also hard to be derived.

There are at least two directions to take in further research using this same dataset: (1) Causality analysis. Ory and Mokhtarian (2006) adopts path analysis approach using cross-sectional rather than panel data, they build two competing models: long commuting determines teleworking, or teleworking determines long commuting. We could do it using Japan's data; (2) Household spillover effect. Teleworking potentially affects the behavior of other household members (analysis of Korea, check Kim, et al., 2016; analysis of United States, check Zhu, 2012), especially whether both teleworker's and teleworker's household members' non-commute trips increase or not is an very important issue, our dataset includes massive information about household members and non-commute trips, which gives an opportunity to explore this issue in Japan.

[13]Image the situation in which individual decides her working location over a year, a month, a week, and over just two days.

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