Impact of telecommuting on mass transit congestion:
the Tokyo case

Hitoshi Mitomo\textsuperscript{a,*}, Toshiya Jitsuzumi\textsuperscript{b}

\textsuperscript{a}Senshu University, 2-1-1 Higashimita, Tama-ku, Kawasaki 214-8580, Japan
\textsuperscript{b}Institute for Posts and Telecommunications Policy, 1-6-19, Azabu-dai, Minato-ku, Tokyo 106-8798, Japan

Abstract

Telecommuting, a dispersed style of commuting enabled by developments in info-communication technology, is becoming increasingly popular among Japanese white-collar employees. According to our estimates, 9–14 million employees will telecommute by 2010, which will result in a 6.9–10.9\% reduction in congestion in Tokyo, Japan. Associated cost savings are equivalent to 7.9–26.4\% of annual spending on public transportation. Due to the considerable size of these positive external effects, some degree of policy support will be necessary to achieve a socially optimal level of penetration by telecommuting. \textcopyright\ 1999 Elsevier Science Ltd. All rights reserved.

Keywords: Telecommuting; Congestion; Social impact; Externality

1. Introduction

Recent developments in info-communication technology have enabled many white-collar employees to work according to a dispersed style of commuting called “telecommuting”. Telecommuters, instead of traveling to a conventional business center, can work at home or at a nearby neighborhood center (hereafter called “satellite office”) and communicate with their conventional workplace using telecommunications.

Telecommuting will have a great and direct impact on those companies that introduce it, for example, it can increase productivity and worker morale (e.g., Caudron, 1992; Mokhtarian, 1991), but also forces the company to adopt new managerial methods (Congressional Office of Technology Assessment, 1994; Nilles, 1988). For employees, telecommuting provides greater flexibility in time management (e.g., Nilles, 1988; Olszewski & Mokhtarian, 1994), and reduces commuting...
stress (Bay Area Air Quality Management District, 1993). In addition, telecommuting can be expected to have far-reaching external effects on society. For example, it improves traffic flows (Kitamura, Nilles, Fleming & Conroy, 1990; Maynard, 1994) and reduces energy consumption (e.g., Mokhtarian, 1991) and air pollution (Nilles, 1988, 1982).

Since core managerial functions in Japan are concentrated in Tokyo, commuters in the Tokyo metropolitan area suffer from severe transit congestion, especially in the peak morning hours. The Japanese government has high hopes on telecommuting as a promising substitute for traditional commuting practices. While telecommuting enables telecommuters to avoid commuting during peak hours (direct internal effects), it also acts to reduce the congestion-related disutility for those who still commute at such times (indirect external effects). Furthermore, as environmental issues have become a focal point of policy talks, the government has come to understand that telecommuting will not only relieve Tokyo's infamous peak-hour congestion, but may also reduce carbon-dioxide emissions resulting from transport activity. Given these positive externalities, the government has begun to subsidize the so-called “telework” projects and provide favorable tax treatment for telework-related properties — actions which clearly demonstrate its positive attitude towards telecommuting.

The existence of externalities suggests that the social marginal benefit of telecommuting is greater than its private marginal benefit. Under these circumstances, a market equilibrium may result in a lower level of penetration than the socially optimal one (Fig. 1) (Mitomo & Jitsuzumi, 1996).
Based on our estimates, the difference between the social and the private marginal benefits is considerable. In such a case, policy support can be economically justified if the costs incurred do not exceed the expected benefit.

The purpose of this paper is to quantify these external effects in the context of mass-transit congestion in the Tokyo metropolitan area. We proceed as follows: First, we predict the number of future telecommuters in Japan and estimate how congestion in the Tokyo metropolitan area would be relieved. Then, we employ railway-commuter disutility functions in order to quantitatively evaluate the congestion reduction effect of telecommuting activity, and show that substantial externalities exist. We find that the external effects are considerably larger than the direct impacts on telecommuters, suggesting a need for policy support by the government.

2. The impact of telecommuting on mass-transit congestion

In this section and the next, we quantify the effect of telecommuting on mass-transit congestion in Tokyo. Our findings can be summarized as follows:

(1) The number of telecommuters by 2010 will be between 9 and 14 million, all of whom will be information workers.

(2) The congestion rate during peak hours will be reduced from 261.1 to 233.2–243.6% of capacity.

(3) Telecommuting will yield benefits equal to approximately 22.5–75.2 billion yen, of which 64–74% accrues to non-telecommuters.

(4) These benefits are equivalent to 7.9–26.4% of household expenditures on public transportation.

2.1. Logistic growth of telecommuters

As telecommuting represents a possible commuting alternative for many types of office workers, we must first determine how telecommuting will penetrate among the workforce, before proceeding to estimate the number of future telecommuters in Japan. Considering that telecommuters perform their work with the aid of information and telecommunications technology, it seems reasonable to presume that telecommuting will spread among information workers, defined as “individuals whose primary economic activity involve the creation, processing, manipulation, or distribution of information”, at least in the short to medium term.

We assume that the number of telecommuters will grow along a logistic curve, which represents a general form of diffusion process.\(^1\) Since no one can predict the growth of telecommuting in the future, we need some scenario settings to cover possible growth outcomes.

We adopt the following three scenarios:

*Scenario 1 (Conservative case):* Eventually, one-third of information workers will telecommute.

*Scenario 2 (Intermediate case):* Eventually, one-half of information workers will telecommute.

*Scenario 3 (Optimistic case):* Eventually, two-thirds of information workers will telecommute.

---

\(^1\) The same methodology was adopted when the number of US telecommuters was predicted by the U.S. Department of Transportation (1993).
The estimated number of telecommuters in Japan is shown in Fig. 2. (See Appendix A for details of the estimation process.) We estimate the percentage of information workers in the total workforce and the fraction of telecommuters among information workers. By multiplying these two values by the predicted total workforce, we obtain the number of future Japanese telecommuters.

2.2. Reduction of mass-transit congestion

Based on the estimated number of telecommuters in Japan, we evaluate how railway congestion in the Tokyo metropolitan area would be relieved by 2010.

The effect of telecommuting diffusion depends on multiple conditions, including how often telecommuters opt to telecommute, whether they telecommute at home or to a satellite office, where they live, and where they worked before beginning to telecommute. For example, telecommuters who work at home would never use the train during peak hours on their telecommuting days. Those who work at satellite offices, however, may still use trains to get there, because automobile commuting remains uncommon in Tokyo. (See Appendix B for details.)

The impact of telecommuting on traffic congestion in the Tokyo metropolitan area can be calculated as listed in Table 1. The table shows that, as telecommuting becomes widespread,
Table 1
Impact of telecommuting on mass-transit congestion in the Tokyo metropolitan area

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Number of commuters in peak hours (riders/h)</th>
<th>Congestion level</th>
<th>Congestion reduction effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No telecommuters(^a)</td>
<td>Our scenarios</td>
<td>No telecommuters(^a)</td>
</tr>
<tr>
<td>Scenario 1</td>
<td>2,425,000</td>
<td>2,258,040</td>
<td>261.6</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>2,425,000</td>
<td>2,202,907</td>
<td>261.6</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>2,425,000</td>
<td>2,161,387</td>
<td>261.6</td>
</tr>
</tbody>
</table>

\(^a\)The figures in the “No telecommuters” columns are obtained from the report of Japan Transport Economics Research Center (1995).

\(^b\)“Congestion Level” is defined as the “Number of Commuters in Peak Hours” divided by the transportation capacity (927,000 riders/h). These figures imply:
- 100% Full capacity (riding a train comfortably — seated, strap-holding, or gripping a pole near an entrance).
- 150% Able to read a newspaper easily although passengers’ shoulders may touch.
- 180% Able to read a newspaper, although passengers may touch.
- 200% Able to read a magazine, although passengers may be considerably jammed together.
- 250% When the train is jolted, passengers are unable to stand straight or move a hand.

railway congestion in the area would fall from 261.1% of capacity to an average 233.2–243.6% by 2010. This represents a decline in congestion of between 6.9 and 10.9%.

3. Welfare gains of telecommuting

Based on the results in the previous section, we quantitatively evaluate how the reduced congestion due to telecommuting would relieve commuters of discomfort, irritation, or impatience arising from excessive crowding and uncomfortable physical proximity; sensations of choking and/or being pushed; and fatigue associated with such congestion. Here, we apply a set of railway-commuter disutility functions, which convert congestion disutility — composed of congestion level and time spent on a congested train — into an equivalent time spent on an uncongested train. Then, multiplying this equivalent uncongested time by the relevant wage rate, we can evaluate the congestion effect in monetary terms.

3.1. Disutility of congestion

Although railway-commuter disutility functions, which transform discomfort in congested trains into a unified cardinal measure, are theoretically plausible, they have not been well tested empirically. Function parameters may be varied according to the data set used, regressional methodology applied, assumptions adopted, and exogenous factors involved; any of these factors
might affect the conclusions we draw. For further discussion we employ the following two models with different parameters in order to show a first-order approximation. However, it will be clear, that our conclusions are not seriously influenced by the differences in parameters used.


\[ U_c = 0.022t(C/100)^2. \]  

Model 2

\[ U_c = 0.005t(C/100)^{3.8}, \]

where \( U_c \) is the commuter disutility in terms of time spent on uncongested trains (min), \( C \) the congestion level (%) and \( t \) the time spent on train (min).

Congestion reduction would probably produce other effects, such as shortened stops at stations, leading to shorter commuting times, which would amplify the degree of disutility reduction. These secondary effects, however, are not considered here.

Table 2 shows our results for disutility reduction among railway commuters continuing to ride trains after the introduction of telecommuting. In the case of no telecommuters, the average expected disutility of commuting would be 6.0 min of riding time in Model 1 and 7.7 min in Model 2, respectively. After telecommuting becomes popular in the Tokyo area, as outlined in our scenarios, these figures are considerably reduced. In the most conservative case, Scenario 1, disutility is reduced by 13.3% in Model 1 (relative to the no-telecommuting case) and 23.7% in Model 2. Under Scenario 3, which assumes the greatest effect for telecommuting, the rates of reduction are 20.6 and 35.4%, respectively.

Note that although the effect is produced by those who become telecommuters, it accrues to those who continue to commute during peak hours (i.e., non-telecommuters).

3.2. Benefit from telecommuting

Multiplying each figure in Table 2 by the average wage rate of Tokyo metropolitan workers, ¥1,962.9/h,\(^2\) yields the welfare gains which accrue to non-telecommuters. However, the figures in each column of Table 2 do not include the impact on telecommuters themselves. Assuming telecommuting to be equal to a “0%-congestion-level/0-minute” railway commute (both for telecommuters working at home or in a satellite office nearby), we obtain a total effect of reduced disutility from telecommuting, both on conventional commuters and telecommuters, as shown in Table 3. The annual base figures are calculated assuming that the annual working hours by 2010 are 1800 h per year (8 h multiplied by 225 d). These figures are equivalent to 7.9–26.4% of annual expenditures of the Tokyo metropolitan area household on public transportation (Management and Coordination Agency, 1998).

Note that these figures are opportunity costs and that income should not actually increase. It is worth pointing out that the majority (62–76%) of the effect of telecommuting would accrue to

\(^2\) This figure is based on data from the Ministry of Labour (1999).
<table>
<thead>
<tr>
<th>Area/limes included</th>
<th>Model 1</th>
<th></th>
<th>Model 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No</td>
<td>Our scenarios*</td>
<td>No</td>
<td>Our scenarios*</td>
</tr>
<tr>
<td>Tokaido:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JR Tokaido, JR Keihin-Tohoku, JR Yokosuka,</td>
<td>5.0</td>
<td>4.3 (−0.7)b</td>
<td>5.4</td>
<td>4.1 (−1.3)b</td>
</tr>
<tr>
<td>Keikyu-Honsen.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Southwest:</td>
<td>5.1</td>
<td>4.5 (−0.7)</td>
<td>5.7</td>
<td>4.4 (−1.4)</td>
</tr>
<tr>
<td>Tokyu Toyoko, Tokyu Mekama, Shintamagawa,</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Odakyu-Odawara.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central:</td>
<td>4.3</td>
<td>3.7 (−0.6)</td>
<td>4.0</td>
<td>3.1 (−1.0)</td>
</tr>
<tr>
<td>JR Chuo, Keio Honsen, Seibu Shinjuku.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northwest:</td>
<td>3.7</td>
<td>3.2 (−0.5)</td>
<td>3.1</td>
<td>2.4 (−0.7)</td>
</tr>
<tr>
<td>Seibu Ikebukuro, Toei Mita, Eidan Yurakucho,</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tobu Tojo.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northeast:</td>
<td>8.0</td>
<td>7.0 (−1.1)</td>
<td>13.4</td>
<td>10.2 (−3.2)</td>
</tr>
<tr>
<td>JR Saikyo, JR Keihin-Tohoku, JR Tohoku, JR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Takasaki.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Joban:</td>
<td>9.5</td>
<td>8.3 (−1.3)</td>
<td>18.5</td>
<td>14.1 (−4.4)</td>
</tr>
<tr>
<td>JR Joban, Tobu Isezaki, Eidan Chiyoda.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sobu:</td>
<td>6.2</td>
<td>5.4 (−0.8)</td>
<td>8.1</td>
<td>6.2 (−1.9)</td>
</tr>
<tr>
<td>JR Sobu, Keisei Honsen, Keisei Oshigai,</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eidan Tozai.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Keiyo:</td>
<td>3.9</td>
<td>3.4 (−0.5)</td>
<td>3.4</td>
<td>2.6 (−0.8)</td>
</tr>
<tr>
<td>JR Keiyo.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yamanote Outer:</td>
<td>9.6</td>
<td>8.3 (−1.3)</td>
<td>18.6</td>
<td>14.2 (−4.4)</td>
</tr>
<tr>
<td>JR Yamanote Outer Line, JR Keihin-Tohoku.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yamanote Inner:</td>
<td>9.4</td>
<td>8.1 (−1.2)</td>
<td>17.9</td>
<td>13.7 (−4.3)</td>
</tr>
<tr>
<td>JR Yamanote Inner Line.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area average</td>
<td>6.0</td>
<td>5.2 (−0.8)</td>
<td>7.7</td>
<td>5.9 (−1.8)</td>
</tr>
</tbody>
</table>

*In the “Our scenarios” columns, the top figures refer to “Scenario 1”, the middle figures refer to “Scenario 2”, and the bottom figures refer to “Scenario 3”.

b Values in parentheses are ΔU, for each scenario.
non-telecommuters, which indicates that positive economic externalities of considerable size do exist.

4. Conclusion

As a form of substitution from physical commuting to virtual commuting, telecommuting is expected to have not only a direct impact on telecommuters but also an indirect impact on society as a whole. In this paper, we have estimated the effect of telecommuting, based on our forecast that the use of this new style of work will soon begin to accelerate, with from 14.5 to 28.3% of the total workforce telecommuting by 2020.

We then selected one of telecommuting’s expected benefits, the relief of mass-transit congestion, and determined that a reduction of 6.9–10.9% could be expected by 2010, which is equivalent to ¥23–¥75 billion of opportunity cost per year. In addition, we were able to determine that approximately two-thirds of these benefits took the form of positive economic externalities.

As shown in the introduction of this paper, the existence of positive externalities suggests that the social marginal benefit of telecommuting is greater than its private marginal benefit. Even in the case where only the effect on congestion is taken into account, the size of telecommuting’s positive external effects seems to be large enough to justify a degree of policy support for this new practice.

When the full range of possible social contributions from telecommuting is considered, including its effects on air pollution, energy consumption, and the greenhouse effect, there can be no doubt that, from the viewpoints of maximizing social welfare or contributing to the sustainability of global society, there is considerable need for some level of pro-telecommuting policy support. As an example, a Pigouvian tax-subsidy that fills up the discrepancy between social and private evaluations of telecommuting would be among the best policies for attaining a socially preferable level of telecommuting. Direct financial support for telecommuting facilities or a subsidy for firms adopting telecommuting may conceivably be a more realistic approach.

This paper suggests that telecommuting is worth pursuing in the coming era of info-communications and demonstrates that there is a quantitative basis for government to design policies which accelerate the penetration of telecommuting.
Appendix A

A.1. Estimation of future Japanese telecommuters

The percentage of information workers in the total workforce, $\alpha$, and the fraction of telecommuters among information workers, $\beta$, are regressed in the following logistic functional forms with the trend $t$ as an explanatory variable; $a, b, c,$ and $d$ are to-be-estimated parameters.

\[
\alpha = \frac{K_a \exp(a + bt)}{1 + \exp(a + bt)}, \quad (A.1)
\]

\[
\beta = \frac{K_b \exp(c + dt)}{1 + \exp(c + dt)}, \quad (A.2)
\]


The upper limits of the growth level, $K_a$ and $K_b$, must be set when estimating the logistic parameters. For $K_a$, considering the difference between the industrial structures in the US and Japan, we set 50% as the upper limit.\(^3\) For $K_b$, we selected $\frac{1}{3}$ for Scenario 1, $\frac{2}{3}$ for Scenario 2, and $\frac{3}{3}$ for Scenario 3.

Table 4 shows the results of an ordinary least-squares regression.

A.2. Estimation of the congestion reduction effect

We introduce the following four exogenous parameters in order to calculate the congestion reduction effect in the Tokyo metropolitan area.

1. Ratio of Tokyo metropolitan telecommuters to the total of such workers in Japan [$\gamma$]: Assuming that telecommuting penetration among information workers will be the same in different regions of Japan, and based on the national population census (Prime Minister’s Office, 1983; Management and Coordination Agency, 1988, 1993), we predict to be 40.97% by 2010.

2. Average telecommuting frequency [$\delta$]: Based on the survey conducted by the Satellite Office Association of Japan (The Satellite Office Association of Japan, 1997), we assume $\delta$ as 0.8 times per week.

3. Ratio of telecommuters who use peak-hour trains on non-telecommuting days [$\varepsilon$]: We assume that the same proportion of telecommuters travel during peak hours as the rest of the population and set this ratio equal to 60%, based on the transportation census (Japan Transport Economics Research Center, 1992).

\(^3\) The upper limit ($K_a$) = 2/3 is used in the estimate by the U.S. Department of Transportation (1993). The latest $\alpha$ for the US is approximately 4/3 of the Japanese figure, therefore the upper limit of Japanese $\alpha$ is set at 1/2, which is 3/4 of 2/3.
Table 4  
Regression results

<table>
<thead>
<tr>
<th>Parameter of Eq. (A.1) ($n = 12$)</th>
<th>$a$</th>
<th>$b$</th>
<th>Adjusted $R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$-87.769\ ( -13.32)^*$</td>
<td>$0.044\ (13.41)^*$</td>
<td>0.942</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter of Eq. (A.2) ($n = 5$)</th>
<th>$c$</th>
<th>$d$</th>
<th>Adjusted $R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>$-601.379\ ( -11.48)^*$</td>
<td>$0.302\ (11.46)^*$</td>
<td>0.970</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>$-534.122\ ( -10.41)$</td>
<td>$0.268\ (10.38)$</td>
<td>0.986</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>$-506.371\ ( -10.02)$</td>
<td>$0.253\ (9.99)$</td>
<td>0.961</td>
</tr>
</tbody>
</table>

*Values in parentheses are $t$-statistics.

4. Ratio of contribution to passenger reduction per telecommuter $[\zeta]$: Just as in the US precedent (U.S. Department of Transportation, 1993), we assume that only 50% of telecommuters would contribute to actual reductions in traffic volume. For example, those who have avoided the usual rush hours might resume commuting, eventually offsetting some of the telecommuting’s congestion reduction effect.

Introducing these four parameters into the following formula, we can estimate the congestion reduction effect in the Tokyo metropolitan area:

\[
\text{The congestion reduction effect in the Tokyo metropolitan area} = \gamma \cdot \delta \cdot \varepsilon \cdot \zeta \] 

Number of telecommuters in Japan.

References


