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# What value do travelers put on connectivity to mobile phone and Internet networks in public transport? Empirical evidence from the Paris region

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## Abstract:

Unlike the drivers of private vehicles, public transport (PT) users may perform secondary tasks during their primary travel activity. Moreover, Information and Communication Technologies may open up “multi-tasking” possibilities by allowing individuals to spend their travel time in more pleasant ways. This article proposes a tentative valuation of connectivity to mobile phone and Internet networks (MPIN) in PT, based on the stated preferences of 501 inhabitants of the Paris region. The surveyed individuals were presented with hypothetical trade-offs between travel time reductions and improvements in MPIN connectivity in PT. Econometric tests show that the values ascribed to better connectivity are higher when PT users perform various tasks with smartphones or tablets during their trips and when they experience a large number of connectivity problems in the reference situation. While heterogeneity between individuals has a minor direct impact, we propose a typology of PT users that captures variations in valuations. On average, the subjective value of travel time would be reduced by 12% if PT users benefited from optimal MPIN connectivity whilst traveling. Alternative “time multipliers” - for types of PT user, gradual connectivity improvements, different device-based tasks – are also proposed. Lastly, we apply our results to a cost-benefit analysis of a current project in the Paris region PT.

## Keywords:

Connectivity; Mobile phone and Internet networks; travel-based multi-tasking; public transport; stated preferences; value of the travel time; time multipliers.

## Glossary:

ICT = information and communication technologies; MPIN = mobile phone and Internet networks; PT = public transport; TBMT = travel-based multi-tasking; SP = stated preferences; VOTT = value of the travel time; ARTT = absolute reduction in travel time; RRTT = relative reduction in travel time; TM = time multiplier.

## 1 Introduction

For economists, transport choices are linked to the utility flows stemming from the different options available to individuals, which depend on both objective travel characteristics such as time and money, and subjective ones, such as comfort, reliability and safety (Ortuzar and Willumsen, 2001; Cascetta and Carteni, 2014). In recent decades, the significant and continuous development of Information and Communication Technologies (ICT)<sup>1</sup> has breathed new life into this strand of research, in four main ways. First, several studies have focused on the substitution of ICT use for travel, fueled by the expectation that this would occur to a significant extent (Mokhtarian and Salomon, 1997), while a consensus has subsequently emerged that complementarity exists between the two (Frag et al. 2007). Secondly, the effects of real-time information on travelers' mode, route or scheduling choices have been extensively analyzed (Chatterjee and McDonald, 2004; Molin and Timmermans, 2006; Chorus et al., 2007; Watkins et al., 2011). Thirdly, scientists have taken advantage of the huge amount of data available from automatic fare collection systems or mobile phones to model travel demand (Aguilera et al., 2014; Zhu et al., 2017). A fourth stream of research – to which this article belongs – looks at the impact of ICT use on mobility practices, with a special emphasis on activities performed with connected devices while traveling in public transport (PT).

Unlike the drivers of private vehicles, PT users may perform additional (secondary) tasks during their main (primary) travel activity (Urry, 2007; Lyons et al., 2007; Keseru et al., 2015). Based on this observation, a growing body of research (see the extensive reviews by Clayton and Jain (2015) and Keseru and Macharis (2017), and the case studies by Berliner et al. (2015); Circella et al. (2012); Ettema and Verschuren (2008) among others) has focused on the interplay between ICT, travel choices, individuals' satisfaction and the concept of what is termed "travel-based multi-tasking" (TBMT)<sup>2</sup>, with a strong interest on the potential for modal shift towards PT (Gamberini et al., 2013; Frei et al., 2015; Malokin et al., 2015; Lee et al., 2019). The overall belief is that ICT, and particularly electronic devices, may help PT users to "consume" their travel time in more pleasant or productive ways (Adoue, 2016; Wardman and Lyons, 2016; Julsrud and Denstadli, 2017; Malokin et al., 2017; Banerjee and Kanafani, 2008; Pawlak et al., 2015; Pawlak et al. 2017; Kouwenhoven and de Jong, 2018). The possibility of working or performing leisure activities in PT thanks to smartphones, tablets or laptops may thus reduce the utility cost of the travel time and make this modal alternative more attractive.<sup>3</sup> More recently, the findings in question have received increasing attention because they could also provide valuable insights into the future use of autonomous cars (Cyganski et al., 2015; Correia et al., 2019).

This paper sets out to assess the value of connectivity to mobile phone and Internet networks (MPIN) on PT in relation to TBMT, from the travelers' perspective. We shall apply a contingent valuation methodology, exploiting original survey data collected in late 2015 from 500 PT users living in the

1 Cohen et al. (2002) define ICT as "a family of electronic technologies and services used to process, store and disseminate information, facilitating the performance of information-related human activities, provided by, and serving the institutional and business sectors as well as the public-at-large". This is a very broad view, in which ICT is seen as using a wide range of digital technologies. Our paper only deals with connectivity to mobile phone and Internet networks and on electronic devices such as smartphones, tablets or laptops.

2 Following Kenyon and Lyons (2007), we define "travel-based multi-tasking" (TBMT) as performing secondary activities during the travel activity, whether it is active (e.g. car driver) or passive (e.g. train passenger). TBMT thus refers to the possibility of doing activities other than traveling ("simultaneous-tasking"), and also to doing a number of different activities during the trip ("task-switching") (Circella et al., 2012).

3 Other studies have found that ICT in PT can cause feelings of isolation and thus reduce the satisfaction resulting from its use (Kraut et al., 1998; Turkle, 2012; Epley et al., 2013).

Paris region. The respondents were presented with hypothetical trade-offs between PT travel time reductions and improvements in the degree of MPIN connectivity, allowing us to propose an indirect assessment valuation of the latter. Our contributions to the literature are twofold.

Whereas “stated preferences” (SP), and to a lesser extent “revealed preferences”, have been analyzed in various contexts for the valuation of many dimensions of PT convenience – in-vehicle or on-platform crowding, reliability, the interior design of vehicles, travel information... (see the extensive review by OECD ITF (2014)) –, studies focused on MPIN connectivity and the potential for TBMT remain scarce. Valuable exceptions are Ettema and Verschuren (2008), Malokin et al. (2017), Kouwenhoven and de Jong (2018) and Varghese and Jana (2018) who show how the possibilities of performing ICT-related activities during the travel time, particularly when there is a good level of connectivity of devices to MPIN, may reduce the utility cost of mobility. This paper adds empirical evidence on this research topic in the special case of urban PT. Metropolitan PT may differ from long-distance journeys in that travel times are generally shorter (which could limit the potential for TBMT), PT is sometimes underground (which may reduce the quality of MPIN connectivity) and seats are not always available (which may impact the way travel time resources are consumed). Even under these specific conditions, we have found that the value put on connectivity improvements is both non-negligible and heterogeneous as regards the use of devices in PT or the perceived quality of MPIN connectivity.

Second, the Paris region case study is particularly interesting in its own right. With more than 3,200 km of subway, regional rail and tramway tracks, around 3,145M trips were made on Parisian rail-based PT in 2015 (OMNIL, 2018). As a consequence, the network is one of the most heavily used in Europe (UITP, 2015). If we consider just Parisian subways, it can be estimated that around 947,000 hours were spent daily in vehicles at that date.<sup>4</sup> Since French official reports highlight the low quality of MPIN connectivity in the Parisian subway, especially as compared to outdoor modes (ARCEP, 2015), it is clear that assessing the hedonic value put by individuals on this travel dimension is of prime interest for both academic and operational purposes. Our results could thus be useful to policy-makers willing to make investments to improve the connectivity to ICT in PT, as is currently planned in the Paris region.<sup>5</sup> Whereas SP have already been analyzed to place a value on train punctuality or in-vehicle crowding in Parisian PT (Kroes et al., 2006, 2013; Haywood and Koning, 2015; de Lapparent and Koning, 2016), we are not aware of any study that proposes an approach of this type for improvements in MPIN connectivity while traveling.

The rest of this paper proceeds as follows: Section 2 introduces the simple theoretical framework used to estimate the value of MPIN connectivity in PT for the purposes of TBMT. The survey data we used to test this model empirically are described in Section 3. The econometric analyses in Section 4 are useful in order to identify the factors that determine the valuation of improved MPIN connectivity in Parisian PT but also to derive central estimates. Section 5 puts our main results in perspective and identifies needs for further research.

4 According to OMNIL (2018), 7,721M passenger-kilometers were travelled on the Paris subway in 2015. Assuming that the 260 working days account for 81% of the annual traffic and considering a uniform average commercial speed of 25.4 km/h, we can estimate the total amount of time daily spent in the subway.

5 The main Paris region PT operator (RATP) is currently deploying the 4G wireless technology over its railway network, with the help of the PT regulator. Initially planned for 2015, this investment program has faced major delays because of civil engineering problems and the complexity of the contractual agreements required with service providers. 4G technology is due to be deployed over the whole PT network in late 2019.

## 2 Modeling framework

### 2.1 The effects on utility of connectivity to mobile phone and Internet networks in public transport

Compared with those presented by DeSherpa (1971), Pawlak et al. (2015) or Wardman and Lyons (2016), among others, the travel time usage and valuation model presented below is very simple. It considers just one representative PT mode and ignores mode choice. The utility function ( $U_i$ ) of traveler  $i$  is specified as:

$$U_i = \alpha + \beta m_i + \delta t_i + \rho X_i \quad (1)$$

where  $m_i$  are the out-of pocket expenditures,  $t_i$  is the travel time spent in PT and  $X_i$  is a vector of personal/trip characteristics that affect the utility for traveler  $i$ .

The parameter  $\delta$  ( $< 0$ ) describes the marginal disutility of the travel time in PT. It is critical here because we model the utility effects of TBMT and MPIN connectivity as follows:

$$\frac{\partial U_i}{\partial t_i} = \delta^k = \delta_0 + \delta_1 C_i^k + \delta_2 M_i^k + \delta_3 M_i^k C_i^k \quad (2)$$

where  $C_i^k$  ( $> 0$ ) is the degree of connectivity to ICT and  $M_i^k$  ( $> 0$ ) is the number of tasks performed by traveler  $i$  during their PT trip with electronic devices. Without loss of generality, both variables are here considered as discrete, with the index  $k=H$  and the index  $k=L$  referring to the “high” and “low” levels of attributes respectively.<sup>6</sup> Moreover, we assume that  $\delta_0 < 0 < \delta_1 C_i^k + \delta_2 M_i^k + \delta_3 M_i^k C_i^k$ .

Equation (2) stipulates that all other things being equal:

- The better the MPIN connectivity in PT ( $C_i^H > C_i^L$ ), the less unpleasant the travel time for individual  $i$  ( $\delta^L < \delta^H < 0$ ), for a given level of TBMT ( $M_i^H = M_i^L$ );
- The larger the number of tasks performed by traveler  $i$  during their PT trip with connected devices ( $M_i^H > M_i^L$ ), the less unpleasant their travel time ( $\delta^L < \delta^H < 0$ ), for a given level of MPIN connectivity ( $C_i^H = C_i^L$ );
- The better the MPIN connectivity ( $C_i^H > C_i^L$ ) and the larger the number of tasks performed with connected devices by traveler  $i$  during their PT trip ( $M_i^H > M_i^L$ ), the less unpleasant their travel time ( $\delta^L < \delta^H < 0$ ).

There are good reasons to assume that MPIN connectivity and the potential for TBMT affect the utility for travelers in proportion to the travel time spent in PT. Ettema et al. (2012), Frei et al. (2015) and Mokhtarian et al. (2015) find that an increase in travel time causes a decrease in the subjective satisfaction with the journey, but performing secondary activities during trips, in particular those involving social interactions, may decrease the dissatisfaction caused by “disagreeable” journeys. For Connolly et al. (2009) and Hislop and Axtell (2009) good connectivity to communication networks can enhance the possibilities for TBMT, which may improve and diversify travel time use. Axtell et al. (2008), Gripsrud and Hjorthol (2012) and Lyons (2013) show in the case of business journeys that PT equipped with “sound” technologies, in particular good MPIN connectivity, can be considered as a

6 Our empirical analysis goes beyond this discrete approach and captures the levels of TBMT and MPIN connectivity.

“mobile office” (Clayton and Jain, 2015), thus increasing the utility of travel. Starting from a theoretical model of time allocation, and coupling different empirical models by means of copula techniques, Pawlak et al. (2017) question the relationships between time allocation and the productivity of activities in the case of business travelers using the railway in the United Kingdom. They show that the use of web-enabled devices during the travel is associated with longer duration working, even if the level of productivity is reported to be slightly lower than in offices. In a confirmation of these findings, de Jong and Kouwenhoven (2018) show that in the Netherlands, between 1988 and 2011, ICT developments have made working in the train almost as productive as at the workplace.

Within our simpler framework, the degree of MPIN connectivity and the associated possibilities of TBMT will affect the value of travel time ( $VOTT^k$ ), i.e. the marginal rate of substitution between time and money resources:

$$VOTT^k = \frac{\frac{\partial U_i}{\partial t_i}}{\frac{\partial U_i}{\partial m_i}} = \frac{\delta^k}{\beta} = \frac{(\delta_0 + \delta_1 C_i^k + \delta_2 M_i^k + \delta_3 M_i^k C_i^k)}{\beta} \quad (3)$$

When the level of MPIN connectivity and/or the degree of TBMT increase, so does the numerator (i.e. it becomes less negative), thus reducing  $VOTT$  ( $VOTT^H < VOTT^L$ ).<sup>7</sup> In other words, we postulate that the generalized cost of PT is lower when travelers have good MPIN connectivity, allowing them to spend their travel time in more productive and/or pleasant ways. This is in line with the existing empirical evidence. Analyzing a survey conducted among PT users in the Netherlands, Ettema and Verschuren (2008) show that listening to music can reduce the  $VOTT$  by 69%. Using the Netherlands Railways Panel, Adjenughwure (2017) finds that trips during which business travelers can read, work or listen to music lead to a reduction of  $VOTT$  of between 42% and 46%. For leisure travelers, the decrease in  $VOTT$  ranges between 6% (when listening to music is possible) and 73% (if they can read). In the case of Mumbai (India), Varghese and Jana (2018) show that the  $VOTT$  of PT commuters can be reduced by 25% if they use smartphones to read and by 37% if they connect to social media. Based on survey data collected in Northern California, Malokin et al. (2017) find that age is positively related to  $VOTT$ : millennials (people born after 1980) have a  $VOTT$  that is 15.5% lower than non-millennials, because the former have a higher propensity to use devices (a proxy for TBMT) during their trips. Analyzing an SP survey collected in the Netherlands, Kouwenhoven and de Jong (2018) show that PT users who state that travel times can be spent “usefully” have a  $VOTT$  that is 20% lower than others, especially car drivers. Recognizing that selection biases might corrupt their empirical analysis, they also estimate that the  $VOTT$  of the users of regional trains or local PT could be reduced by 3% and 5% respectively if they have access to a computer during their trip.<sup>8</sup>

Limitations in our survey data prevent us from estimating  $\beta$  and therefore making a direct assessment of  $VOTT$ . For this reason, we have applied an indirect approach derived from the contingent valuation literature instead.

7 The parameter  $\beta$  could theoretically depend on the level of connectivity to MPIN in PT. During our empirical exercise we only examined the potential influence of PT fares on the value put on connectivity improvements.

8 Considering the case of Great Britain, Steer Davies Gleave (2016) finds that train users are willing to pay 13-17% more for their fare to improve the Internet service from “no connection” to “low level connection”. The fare increase to improve the service from “low level” to “medium level” connection was 4-5%.

## 2.2 The value of connectivity to mobile phone and Internet networks in public transport

Historically, the contingent valuation methodology was designed to assess the value of “non-market goods”, particularly in the field of environmental economics (Hanemann et al., 1991; Haab and McConnell, 2002). In contrast to analyses that examine real behaviors (revealed preferences), it presents individuals with hypothetical scenarios in order to determine the equivalent or compensatory variation in economic resources that makes them “indifferent” between a variety of situations, hence studying their SP.

For reasons that will be made clear in the next Section, our contingent scenarios involved trade-offs between improved MPIN connectivity and reduced travel times, instead of more expensive PT fares as was the case in Steer Davies Gleave (2016) for instance. More precisely, we want to determine the “absolute reduction in travel time” ( $ARTT_i$ ) that equalizes the utility flows experienced by individual  $i$  across “optimally” (index  $o$ ) and “as currently” (index  $c$ ) connected PT ( $C_i^o > C_i^c$ ):

$$U_i^o = \alpha + \beta m_i + (\delta_0 + \delta_1 C_i^o + \delta_2 M_i + \delta_3 M_i C_i^o) t_i + \rho X_i = \alpha + \beta m_i + (\delta_0 + \delta_1 C_i^c + \delta_2 M_i + \delta_3 M_i C_i^c) t_i \quad (4)$$

where the degree of TBMT ( $M_i$ ) is now exogenous.

Equation (4) can be re-written as:

$$ARTT_i = t_i \quad (5)$$

It is straightforward to show that the valuation for the MPIN connectivity is an increasing function of the PT travel time (because  $C_i^c - C_i^o < 0$  and  $\delta_0 + \delta_1 C_i^c + \delta_2 M_i + \delta_3 M_i C_i^c < 0$ ). Moreover, simple manipulations give:

$$\frac{\partial ARTT_i}{\partial C_i^c} = \frac{t_i (\delta_1 + \delta_3 M_i) (\delta_0 + \delta_1 C_i^o + \delta_2 M_i + \delta_3 M_i C_i^o)}{(\delta_0 + \delta_1 C_i^c + \delta_2 M_i + \delta_3 M_i C_i^c)^2} < 0 \quad (6)$$

and:

$$\frac{\partial ARTT_i}{\partial M_i} = \frac{t_i (C_i^c - C_i^o) (\delta_0 \delta_3 - \delta_2 \delta_1)}{(\delta_0 + \delta_1 C_i^c + \delta_2 M_i + \delta_3 M_i C_i^c)^2} > 0 \quad (7)$$

because  $(\delta_0 \delta_3 - \delta_2 \delta_1) < 0$  if  $\delta_0 < \delta_2 \delta_1 / \delta_3$ , which is the case with our assumptions.

Equation (6) stipulates that individuals ask for a lower travel time reduction in exchange for optimal MPIN connectivity whenever they benefit from a higher reference level of connectivity. Equation (7) implies that PT users place more value on optimal connectivity when they perform more tasks with web-enabled devices during their trip.

Although the empirical analysis in Section 4 will test these conjectures, our preferred valuation of connectivity to ICT is the “relative reduction in travel time” ( $RRTT_i$ ):

$$RRTT_i = \frac{ARTT_i}{t_i} \quad (8)$$



As above, one can demonstrate that  $RRTT_i$  depends positively on  $M_i$  and negatively on  $C_i^c$ . Above all, Equation (8) may be re-written in order to formalize the link between  $RRTT_i$  and the “time multiplier” ( $TM_i$ ), a classical indicator used to assess the value of the quality of PT (OECD ITF, 2014):

$$RRTT_i = 1 - TM_i = 1 - \frac{(\delta_0 + \delta_1 C_i^o + \delta_2 M_i + \delta_3 M_i C_i^o)}{(\delta_0 + \delta_1 C_i^c + \delta_2 M_i + \delta_3 M_i C_i^c)} \quad (9)$$

The time multiplier is the marginal rate of substitution between “as currently” and “optimally” connected travel times (i.e. the ratio between marginal disutilities of time). Let us assume that  $RRTT_i$  is equal to 0.15, which means that  $TM_i$  is 0.85. The utility cost of one minute spent in PT with optimal MPIN connectivity is in this case equivalent, from the individuals’ perspective, to 85% of the disutility arising from the same minute spent with the current (lower) connectivity. In practice, it suffices to apply the estimated  $TM_i$  to a benchmark  $VOTT$  to translate the subjective value of MPIN connectivity in PT moderated by the degree of TBMT into a monetary metric. This may be valuable in the framework of cost-benefit analyses of policies aimed at improving connectivity to communication networks in PT, as discussed in Section 5.

### 3 Data

#### 3.1 Sample characteristics

Our data come from an on-line survey conducted in 2015 with the help of the main PT operator in the Paris region (RATP), via two distinct channels.<sup>9</sup> First, a link to the questionnaire was included in the RATP monthly newsletter which is emailed to around 400,000 travel pass holders. Because only 403 individuals took part in the survey, an additional 601 PT users were recruited via a dedicated access panel. Unfortunately, only 68% of the 1,004 individuals completed the valuation question and many travelers did not provide any information on their in-vehicle travel time. After removing some inconsistent answers, we finally obtained a dataset of 501 PT users to work on. Table 1 reports the personal and travel characteristics of the individuals in our sample. These variables can be considered as controls when estimating the value put on improved MPIN connectivity in PT, in line with findings in the existing literature (Keseru and Macharis, 2017) as well as our valuation procedure. The questions on travel characteristics related to the daily morning PT commuting trip.

Males accounted for 32% of the sample, whose mean age is 38 years old. Keseru and Macharis (2017) report that both these personal characteristics may affect the degree of TBMT in PT, hence the value individuals put on MPIN connectivity. Residents of the City of Paris had a moderate presence (20%), 44% of the individuals have at least a Bachelor’s degree, and 33% were executives. Again, it is possible that educated individuals and/or executives differ from others with respect to the use of electronic devices during their trips (Wardman and Lyons, 2016). Most of the respondents

<sup>9</sup> These data were collected in the context of work on a PhD thesis (Adoue, 2016) investigating how PT travelers use connected devices to mitigate their daily spatial and temporal constraints. Combining qualitative (in-depth semi-directive interviews) and large-scale quantitative surveys, Adoue (2016) confirms that connected mobility allows travelers to carry out in PT some activities that they usually perform “outside”. Connected mobility also improves the feeling of having control over one’s daily mobility thanks to the provision of personalized information. Some questions in the quantitative survey were dedicated to assessing the value put on improvements in MPIN connectivity in PT. Since this choice experiment was not analyzed in Adoue (2016), we shall present some new findings here.



lived as part of a couple (86%) and 34% of them had at least one child. These variables control for the scheduling of individuals' activities because our hypothetical scenarios result in changes in travel times. Also, people with children may be less likely to travel alone, which could reduce their potential for connected TBMT. On the other hand, the need for coordination and for communication between household members is higher when the household includes children. This may lead to a larger degree of connected TBMT for parents who travel alone. Finally, around 85% of the sample owned a smartphone and 52% a tablet. Even if the survey did not elicit this information, it is worth noting that affordable and "unlimited" telecom packages (for calls and text messages and allowing for a huge volume of Internet data to be downloaded) were already the rule in France in 2015 (Toustou, 2015). Put differently, the use of electronic devices in PT is probably not limited by monetary considerations, but merely by personal characteristics or MPIN connectivity.

**Table 1 – Personal and morning commute trip characteristics**

Variables	Our sample (2015) (n=501)			All PT commuters (EGT, 2010) (n=4,091)			Difference (sample-EGT)
	%	Av.	Std. Dev.	%	Av.	Std. Dev.	
<b>Male</b>	31.7	-	-	47.8	-	-	-16.1***
<b>Age (years)</b>	-	38.2	13.3	-	38.0	12.3	0.1
<b>Live in Paris municipality</b>	19.6	-	-	28.5	-	-	-9.0***
<b>At least Bachelor's degree</b>	44.1	-	-	40.4	-	-	3.8*
<b>Executives</b>	32.9	-	-	28.2	-	-	4.7**
<b>Live as part of a couple</b>	86.2	-	-	64.0	-	-	22.3***
<b>Have children</b>	33.7	-	-	39.6	-	-	-5.9***
<b>Own a motor vehicle</b>	72.7	-	-	63.1	-	-	9.6***
<b>Door-to-door travel time (minutes)</b>	-	53.2	24.2	-	55.9	26.3	-2.7**
<b>Use only subway</b>	16.6	-	-	21.6	-	-	-5.0***
<b>Use only regional trains</b>	18.8	-	-	16.0	-	-	2.8*
<b>Use only outdoor public transport</b>	15.8	-	-	14.4	-	-	1.4
<b>Own a smartphone</b>	85.0	-	-	NA			
<b>Own a tablet</b>	52.0	-	-	NA			
<b>Public transport travel time (minutes)</b>	-	39.1	22.3	NA			
<b>Travel time seen as "wasted" time</b>	66.0	-	-	NA			
<b>Seated during the main trip</b>	44.0	-	-	NA			
<b>Daily use of public transport</b>	94.0	-	-	NA			
<b>Trip within the same travel zone</b>	38.0	-	-	NA			

Notes: 1) Student's t-test was used to compare means and the Chi-squared test was used to compare frequencies; 2) \*\*\*:  $p < 0.01$ , \*\*:  $p < 0.05$ , \*:  $p < 0.10$ ; 3) "NA" stands for not available; 4) The 4,091 observations in the EGT survey have been weighted and extrapolated to around 1.4M PT commuters.

Sources: survey data from Adoue (2016) and EGT (IDFM-OMNIL-DRIEA, 2010).

If we now consider travel characteristics, the respondents reported spending 39 minutes on average in PT, and a total door-to-door travel time of 53 minutes.<sup>10</sup> It should be borne in mind that individuals' travel time budget is expected to increase their  $ARTT_i$ , although heterogeneity in the perceived utility cost of travel time can moderate this effect. In this connection, 66% of the respondents considered their trip to be as a source of "wasted and unproductive" time. Although the

10 Perceived PT travel times are known to differ significantly from actual travel times because of psychological factors and trip characteristics (Li, 2003). Nevertheless, perceived duration is key to understanding travel behavior and is taken as reference in our approach which focuses on the travel experience.

survey does not allow us to reconstruct the different legs, we can state that 17% of the individuals used only subways for their morning commute trip, 19% used only regional trains and 16% used only outdoor PT (buses, streetcars), the rest of the sample using combinations of different modes (including cars or bicycles). Interestingly, official indicators that describe the quality of MPIN in France differ across PT modes (ARCEP, 2015). However, whatever dimension is considered, subways systematically performed worse than regional trains in 2015, the latter exhibiting poorer connectivity compared to outdoor PT.<sup>11</sup> Having said this, PT is mainly used on a daily basis (94%) and 44% of individuals are always seated during their morning trip, and one can assume that comfortable journeys facilitate TBMT (Haywood et al., 2017).<sup>12</sup> Moreover, 73% of the sample owned a motor vehicle and sometimes experienced “less connected” trips. Lastly, we constructed a proxy for the price of the PT travel pass, which is extremely difficult to estimate in the Paris region. Around 38% of individuals lived and worked in the same travel zone. It can be hypothesized that these individuals’ expenditure was lower given the PT pricing structure in the Paris region in 2015.<sup>13</sup> As such, they may be less likely to demand a good level of MPIN connectivity than those who spend more on fares.

A potentially important issue is how representative this sample is of the entire population of PT commuters in the Paris region. We test this using the 2010 household mobility survey (“Enquête Globale Transport”). Table 1 shows that our sample exhibits many biases in this respect. Whereas the over-representation of females is usual in PT surveys, important differences in residence locations, family situations and motor vehicle ownership rates are apparent. In contrast, divergences in door-to-door travel times or in modal shares are fairly minor, even though they are statistically significant. Lastly, we do not observe any significant difference in individuals’ ages. In spite of these issues, the econometric tests in Section 4 conclude that individual heterogeneity does not directly impact the value travelers put on improved MPIN connectivity in PT. We can hence base our empirical analysis on the (un-weighted) sample shown in Table 1.

### *3.2 Connectivity to communication networks and travel-based multi-tasking*

Two crucial ingredients for our valuation exercise are the benchmark level of MPIN connectivity in PT ( $C_i^c$ ) and the degree of individuals’ TBMT ( $M_i$ ). With regard to the latter, travelers were presented with a list of 17 activities and had to select those they performed (on a regular or daily basis) in PT during their morning commute trip. Individuals performed an average of 4 different tasks during their travel time (Table 2), with, however, a high degree of heterogeneity. While 35% of travelers performed 2 (or fewer) activities, around 18% of the sample performed 6 (or more) tasks. The most frequently quoted activities were sending/receiving text messages (63%), listening to music (46%), reading printed books (42%) or newspapers (40%). In contrast, very few individuals used their travel time to make business phone calls (3%), to reading/writing business emails (5%), working on devices

11 The French communications industry regulator uses three different indicators to compare the quality of ICT services in transportation (ARCEP, 2015): the proportion of phone calls that are uninterrupted for 2 minutes, the percentage of text messages that are received within 30 seconds, and the proportion of web pages that are loaded within 30 seconds.

12 Interviewing 1,000 Paris subway users, Haywood et al. (2017) show that “non-polychronic” use of travel time is one of the most disturbing results of in-vehicle crowding. High passenger densities may thus prevent travelers from reading journals and books, or using their smartphones during their trips.

13 In 2015, the price of travel passes in the Paris region depended on five concentric zones, with increasing prices according to the distances traveled. The pricing structure became flat in 2016. Our proxy ignores employers’ refunding schemes that may cover as many as 50% of travel passes.

(6%) or watching videos (7%). Although informative, we did not use these precise activities as determinants of  $ARTT_i$  during our econometric study. We have preferred to use this information as a basis in order to propose more global TMBT variables.<sup>14</sup>

First, we differentiated between activities depending on whether or not they require an electronic device. On average, individuals performed 3 different tasks during their PT trips with a smartphone, tablet or laptop, compared to 1 activity without a device. Half of the sample performed 2 or fewer device-based activities and 38% of the individuals never performed non-electronically assisted tasks. Second, we have also distinguished between device-based activities according to the required degree of MPIN connectivity. For instance, playing video-games in PT is still feasible without any Internet connection if the digital content has been downloaded beforehand. In contrast, it is difficult to have the instantaneous communications that are available on social media or surf the Internet with poor connectivity. We have therefore described those activities that may be performed without any MPIN connection as “offline» and those that require some continuity in connectivity as “online”. While recognizing that our typology of device-based tasks is discretionary, individuals are nevertheless more likely to perform “online” (2.1) than “offline” activities (0.9). Lastly, we considered the differentiated impact of the purposes of the tasks. Individuals who use devices in PT for leisure activities may place a different value on MPIN connectivity compared to travelers whose TBMT is focused on communications. Even if our division of tasks is open to criticism in this case too, electronic devices are predominantly used for personal communications (1.6 tasks on average), and less for entertainment purposes (1.3). The number of leisure activities conducted without any device is non-negligible (0.9) and business tasks are only rarely reported (0.2 activities by merging activities that are performed with and without devices).<sup>15</sup>

We employed two types of variables to control for the current level of MPIN connectivity in PT ( $C_i^c$ ). As we have already seen, we can exploit variations in the objective degree of connectivity to communication networks, as reported by ARCEP (2015) and here approximated by means of the different PT modes used by travelers (see Table 1). Above all, we have relied on information about the number of problems faced by individuals when trying to use their devices in PT. The survey participants were presented with a list of activities that can be performed with a smartphone, laptop or tablet and had to choose a maximum of two items for which they faced major difficulties because of low MPIN connectivity. Table 3 illustrates that travelers reported an average of 1.2 connectivity problems (19% of the sample stated that they were never disturbed and 43% selecting the maximum of 2 items). When looking in detail at the types of activities that were affected, travelers reported facing major difficulties when making phone calls (43% of the sample) and sending or receiving text messages (18%). In contrast, listening to music and writing/reading emails did not seem to pose many problems to PT users (3% and 4% respectively).<sup>16</sup>

**Table 2 – Variety of tasks performed in PT, with and without devices**

Type of	Connectivity	Activity	Av.	St. Dv.	Min.	Max.
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14 Our TBMT variables only describe the number of tasks performed in PT and not their duration.

15 The low percentage of business tasks reported within our ample is probably due to the fact that travel times in PT are relatively short in comparison with interurban, long-distance journeys.

16 Descriptive analyses (not reported here) show that people who perform a given activity generally report more connectivity problems than individuals who do not perform this activity. For instance, 38% of the travelers who listen to the radio in PT reported a connectivity problem for this, compared to 11% of those who do not listen to the radio.

<b>activity:</b>	<b>needs:</b>	<b>purposes:</b>				
<i>Working on printed documents</i>	<i>None</i>	<i>Work</i>	<i>0.10</i>	<i>0.30</i>	<i>0</i>	<i>1</i>
<i>Reading books</i>	<i>None</i>	<i>Leisure</i>	<i>0.42</i>	<i>0.49</i>	<i>0</i>	<i>1</i>
<i>Reading newspapers</i>	<i>None</i>	<i>Leisure</i>	<i>0.40</i>	<i>0.49</i>	<i>0</i>	<i>1</i>
<i>Playing pen and paper games</i>	<i>None</i>	<i>Leisure</i>	<i>0.10</i>	<i>0.30</i>	<i>0</i>	<i>1</i>
<i>Reading e-books</i>	<i>“Offline”</i>	<i>Leisure</i>	<i>0.10</i>	<i>0.29</i>	<i>0</i>	<i>1</i>
<i>Listening to music</i>	<i>“Offline”</i>	<i>Leisure</i>	<i>0.46</i>	<i>0.50</i>	<i>0</i>	<i>1</i>
<i>Watching videos</i>	<i>“Offline”</i>	<i>Leisure</i>	<i>0.07</i>	<i>0.26</i>	<i>0</i>	<i>1</i>
<i>Playing video games</i>	<i>“Offline”</i>	<i>Leisure</i>	<i>0.22</i>	<i>0.42</i>	<i>0</i>	<i>1</i>
<i>Sending/receiving personal text messages</i>	<i>“Online”</i>	<i>Communication</i>	<i>0.63</i>	<i>0.48</i>	<i>0</i>	<i>1</i>
<i>Visiting social media</i>	<i>“Online”</i>	<i>Communication</i>	<i>0.31</i>	<i>0.46</i>	<i>0</i>	<i>1</i>
<i>Sending/receiving personal emails</i>	<i>“Online”</i>	<i>Communication</i>	<i>0.34</i>	<i>0.48</i>	<i>0</i>	<i>1</i>
<i>Surfing the Internet</i>	<i>“Online”</i>	<i>Leisure</i>	<i>0.29</i>	<i>0.45</i>	<i>0</i>	<i>1</i>
<i>Sending/receiving business emails</i>	<i>“Online”</i>	<i>Work</i>	<i>0.05</i>	<i>0.21</i>	<i>0</i>	<i>1</i>
<i>Listening to the radio</i>	<i>“Online”</i>	<i>Leisure</i>	<i>0.14</i>	<i>0.34</i>	<i>0</i>	<i>1</i>
<i>Making personal phone calls</i>	<i>“Online”</i>	<i>Communication</i>	<i>0.30</i>	<i>0.46</i>	<i>0</i>	<i>1</i>
<i>Making business phone calls</i>	<i>“Online”</i>	<i>Work</i>	<i>0.03</i>	<i>0.16</i>	<i>0</i>	<i>1</i>
<i>Working on e-device</i>	<i>“Offline”</i>	<i>Work</i>	<i>0.06</i>	<i>0.24</i>	<i>0</i>	<i>1</i>
<b>Total number of activities in PT (=1+2)</b>			<b>4.01</b>	<b>2.81</b>	<b>0</b>	<b>15</b>
<b>Activities in PT without device (1=6+8)</b>			<b>1.01</b>	<b>0.99</b>	<b>0</b>	<b>4</b>
<b>Activities in PT with devices (2=3+4=5+7+9)</b>			<b>3.00</b>	<b>2.51</b>	<b>0</b>	<b>12</b>
<b>Activities in PT with “offline” devices (3)</b>			<b>0.91</b>	<b>1.00</b>	<b>0</b>	<b>5</b>
<b>Activities in PT with “online” devices (4)</b>			<b>2.09</b>	<b>1.86</b>	<b>0</b>	<b>8</b>
<b>Work activities in PT with devices (5)</b>			<b>0.14</b>	<b>0.50</b>	<b>0</b>	<b>3</b>
<b>Work activities in PT without device (6)</b>			<b>0.10</b>	<b>0.30</b>	<b>0</b>	<b>1</b>
<b>Leisure activities in PT with devices (7)</b>			<b>1.27</b>	<b>1.29</b>	<b>0</b>	<b>6</b>
<b>Leisure activities in PT without device (8)</b>			<b>0.92</b>	<b>0.91</b>	<b>0</b>	<b>3</b>
<b>Communication activities in PT with devices (9)</b>			<b>1.59</b>	<b>1.42</b>	<b>0</b>	<b>4</b>

Source: authors' calculations from survey data.

With reference to the TBMT variables presented above, we can differentiate between these problems according to the required level of connectivity and the purposes of the activities.<sup>17</sup> When we do this, it is apparent that most of the problems involve “online” tasks rather than “offline” tasks, in a ratio of 5 to 1, for obvious reasons. Since all communication activities require continuous connectivity, they were more frequently mentioned by travelers (0.7) than leisure tasks (0.5), the latter frequently being performed with “offline” devices (e.g. listening to music or playing video games). It is worth noting that the level of MPIN connectivity ( $C_i^c$ ) and the degree of individuals' TBMT ( $M_i$ ) are positively correlated (see Appendix 7.2). Even if this relationship is moderated by many personal factors and calls for further research, one can postulate that the larger the number of device-based activities are performed in PT, the more connectivity problems will be reported.<sup>18</sup>

**Table 3 – Connectivity problems when using electronic devices in PT**

17 Connectivity problems with work activities are barely distinguishable from connectivity problems with communications, so we have only considered the latter in Table 3.

18 Survey participants also assigned a “satisfaction score” to the quality of 2G/3G wireless networks in Parisian PT, but we have not used this variable on three grounds. First, although high satisfaction scores increase the valuations put on connectivity improvements, goodness-of-fit statistics suggest that using the number of connectivity problems is more appropriate. Second, the satisfaction score is highly correlated with the PT modes used by individuals (higher for outdoor PT, lower for subways). Finally, the number of connectivity problems is easier to understand and operationalize, as shown in Section 5.

<b>Connectivity Problems</b>	<b>Connectivity Needs</b>	<b>Activity Purposes:</b>	<b>Av.</b>	<b>St. Dv.</b>	<b>Min.</b>	<b>Max.</b>
<i>Texting (SMS)</i>	<i>“Online”</i>	<i>Communication</i>	<i>0.18</i>	<i>0.38</i>	<i>0</i>	<i>1</i>
<i>Emails</i>	<i>“Online”</i>	<i>Communication</i>	<i>0.04</i>	<i>0.19</i>	<i>0</i>	<i>1</i>
<i>Music</i>	<i>“Offline”</i>	<i>Leisure</i>	<i>0.03</i>	<i>0.18</i>	<i>0</i>	<i>1</i>
<i>Videos</i>	<i>“Offline”</i>	<i>Leisure</i>	<i>0.14</i>	<i>0.35</i>	<i>0</i>	<i>1</i>
<i>Video games</i>	<i>“Offline”</i>	<i>Leisure</i>	<i>0.06</i>	<i>0.24</i>	<i>0</i>	<i>1</i>
<i>Radio</i>	<i>“Online”</i>	<i>Leisure</i>	<i>0.15</i>	<i>0.36</i>	<i>0</i>	<i>1</i>
<i>Social media</i>	<i>“Online”</i>	<i>Communication</i>	<i>0.06</i>	<i>0.24</i>	<i>0</i>	<i>1</i>
<i>Phone calls</i>	<i>“Online”</i>	<i>Communication</i>	<i>0.43</i>	<i>0.50</i>	<i>0</i>	<i>1</i>
<i>Surfing the Internet</i>	<i>“Online”</i>	<i>Leisure</i>	<i>0.15</i>	<i>0.36</i>	<i>0</i>	<i>1</i>
<b>Total number of connectivity problems (=1+2=3+4)</b>			<b>1.24</b>	<b>0.75</b>	<b>0</b>	<b>2</b>
<b>Connectivity problems with “offline” activities (1)</b>			<b>0.24</b>	<b>0.47</b>	<b>0</b>	<b>2</b>
<b>Connectivity problems with “online” activities (2)</b>			<b>1.00</b>	<b>0.75</b>	<b>0</b>	<b>2</b>
<b>Connectivity problems with communication activities (3)</b>			<b>0.70</b>	<b>0.68</b>	<b>0</b>	<b>2</b>
<b>Connectivity problems with leisure activities (4)</b>			<b>0.54</b>	<b>0.63</b>	<b>0</b>	<b>2</b>

Source: authors' calculations from survey data.

### 3.3 A typology of travelers

The number of tasks performed in PT and/or the level of connectivity problems could fail to capture some important characteristics. For instance, the value put on MPIN connectivity may be impacted by the way limited time resources are consumed by individuals in other locations. Perceived connectivity and TBMT could also depend on individual skills as regards device use. Since our survey included questions about these “non-travel” characteristics, it may be worthwhile to include this information in our analysis. In order to restrict the number of parameters to be estimated, however, we decided to identify groups of individuals on the basis of hierarchical cluster analysis (HCA; see Ward, 1963). A similar method has been proposed in the Norwegian context where Julsrud and Denstadli (2017) identified three groups of travelers according to their use of devices whilst traveling (“Active users”, “Passive users” and “Low use”). In the framework of its Observatory of French mobility, Keolis (2016) also identified three groups of individuals depending on their expectations about the quality of digital services in PT (“Digi’mobiles”, “Connectés” and “Offlines”).

Here we shall present only the main results of the HCA, as the whole empirical strategy has been detailed in Bounie (2018). The binary input factors were: ownership of smartphones and tablets, individuals’ beliefs regarding their aptitude for ICT (“good” or “bad”), various dummies describing whether PT users perform some activities (regrouped here into the general categories of “work”, “communication”, “entertainment” and “information”<sup>19</sup>) with and/or without the help of electronic devices, at home and/or in PT. As is clear from Table 4, three categories of PT users emerge. First, “ultra-connected” individuals (26% of the sample) who feel comfortable with ICT. They perform the majority of their activities with smartphones or tablets, especially for entertainment and

<sup>19</sup> As compared to the typology of tasks presented in Table 2, the “Information” category also includes “Surfing the Internet” and “Reading newspapers”.

informational purposes, both at home and in PT. In contrast, “poorly-connected” individuals (19% of the sample) are less likely to own a smartphone or a tablet and have more difficulty harnessing the many potentialities of ICT. These people work and read information in more “traditional” ways (without any device). Lastly, most of the sample (55%) belongs to the “combining” users category. These travelers make use of both ICT-based and traditional media to work, to read information and for recreational purposes.

If we look at the personal characteristics behind the types of PT users (see Appendix 7.1), poorly-connected individuals are mostly women, older than the average, less educated, less likely to use subways or to own motorized vehicles. Table 4 and Appendix 7.1 also show that the types of users differ considerably with respect to the perceived quality of MPIN connectivity and to the number of tasks performed in PT, with or without devices. This is especially true for poorly-connected travelers who are less likely to use smartphones or tablets during their trips (1 device-based activity vs. 3.4 for others) and who report fewer connectivity problems (0.9 vs. 1.3 for others). In contrast, ultra-connected and combining individuals share many similarities in these respects, except that the former report less non device-based activities (1.3 tasks without any device vs. 0.4). Put another way, this cluster of PT users may be useful in order to capture idiosyncrasies in both TBMT and reference levels of MPIN connectivity.

**Table 4 – Typology of PT users**

	<b>Ultra-connected</b>	<b>Combining</b>	<b>Poorly-connected</b>	<b>Whole sample</b>
<b>Sample share</b>	26%	55%	19%	100%
<b>Own a smartphone</b>	100%	100%	22%	85%
<b>Own a tablet</b>	53%	61%	29%	52%
<b>Aptitude for ICT</b>	91%	89%	5%	73%
<b>Communication tasks in PT and at home</b>	100%	100%	89%	98%
<b>Work tasks in PT and at home</b>	40%	53%	32%	46%
<i>Only with devices</i>	47%	30%	3%	30%
<i>Only without device</i>	24%	27%	84%	34%
<i>With both</i>	29%	43%	13%	36%
<b>Entertainment tasks in PT and at home</b>	94%	100%	94%	97%
<i>Only with devices</i>	63%	1%	10%	17%
<i>Only without device</i>	6%	8%	43%	15%
<i>With both</i>	31%	91%	47%	68%
<b>Information tasks in PT and at home</b>	70%	100%	87%	90%
<i>Only with devices</i>	60%	0%	1%	12%
<i>Only without device</i>	10%	23%	87%	33%
<i>With both</i>	30%	77%	12%	55%
<b>Total number of activities in PT</b>	3.8	4.8	2.1	4.0
<b>Activities in PT without device</b>	0.4	1.3	1.1	1.0



<b>Activities in PT with devices</b>	3.4	3.5	1.0	3.0
<b>Total number of connectivity problems in PT</b>	1.3	1.3	0.9	1.2

Source: authors' calculations from survey data, see details in Bounie (2018).

### 3.4 Procedure for value assessment

The survey participants were asked whether they would be interested in an improvement in the degree of MPIN connectivity in PT. Around 86% replied that they would, and were then presented with the following hypothetical choice:

*“Which improvement would you prefer: optimal connectivity to mobile phone and Internet networks in PT, or a 10 minute decrease in your (morning) PT travel time?”*

In line with the “double-bounded” framework (Hanemann et al., 1991), follow-up questions were then asked depending on individuals’ responses to this first scenario. Those who opted for the 10 minute travel time saving option were presented with a second choice experiment with a travel time reduction of 5 minutes. For these individuals, the valuation exercise stopped after this second question. In contrast, travelers who initially selected the optimal connectivity option were then presented with successively larger travel time savings (of 15, 20 and 25 minutes). For these people, the choice experiment stopped as soon as they rejected the optimal connectivity option. Consequently, individuals’ answers to these hypothetical scenarios inform us about the value they put on MPIN connectivity, as approximated by  $ARTT_i$  (see Equation (5)).

The hypothetical gain proposed to PT users is subjective because each individual may define the “optimal level of connectivity” very differently. We believe, however, that the number of connectivity problems and other variables available in the survey may control for such heterogeneity in perceptions. Moreover, using a temporal payment vehicle instead of a monetary one could greatly improve the accuracy of SP, which is a major limitation of the contingent valuation methodology (Kanninen, 1995; Haab and McConnell, 2002). First, we should remember that the on-line surveys were disseminated with the help of the Paris region PT operator.<sup>20</sup> Therefore, individuals may have seen hypothetical scenarios based on monetary bids as an attempt to increase PT fares, with a potentially high rejection rate. Second, proposing more expensive PT fares would incentivize some individuals to free-ride on others’ contributions (“strategic bias”). Finally, some travelers may consider MPIN quality to be so low in PT that they prefer to interrupt their call before entering the subway station, and to abstain from calling while traveling. Put differently, these individuals are making a trading-off between travel time and MPIN connectivity, which should reduce the “hypothetical bias”.

Table 5 shows the distribution of individuals’ answers to these choice experiments. The majority of PT users (59%) chose the travel time savings option twice, as their  $ARTT_i$  was under 5 minutes. The second most represented category (22%) is made of PT users who initially preferred the 10 minute decrease in travel time, then optimal connectivity when presented with lowest time saving (5 minutes). Lastly, the percentage of individuals who placed a high value on MPIN connectivity (because they asked for travel time reductions of at least 10 minutes) is moderate (19%). By

<sup>20</sup> Using the RATP electronic newsletter to elicit preferences for optimal connectivity to MPIN in PT may be problematic. Since 95% of the regional inhabitants had access to the Internet in 2015 either at home or at the workplace (Brice et al., 2015) we argue, however, that any selection bias is moderate.



censoring the upper and lower intervals by applying reasonable thresholds (e.g. 0 minutes for “below 5 minutes” and the actual travel time in PT for the “above 25 minutes”), an average  $ARTT_i$  of 6 minutes was obtained. When individuals’ responses were normalized by their PT travel times, the average  $RRTT_i$  was equal to 17%. In other terms, one could apply a time multiplier of 0.83 to the benchmark  $VOTT$  if MPIN connectivity were optimal in the Paris region’s PT.

**Table 5 – Absolute reductions in travel time (ARTT)**

ARTT intervals (in minutes)	<5	5-10	10-15	15-20	20-25	>25	ARTT
<b>Whole sample</b>	58.9%	22.2%	6.0%	6.8%	2.0%	4.2%	6.0
<i>PT time &lt; 30 min.</i>	63.8%	23.3%	6.1%	4.9%	1.2%	0.6%	3.8
<i>PT time &gt; 30 min.</i>	56.5%	21.6%	5.9%	7.7%	2.4%	5.9%	7.1
<i>0-1 connected tasks</i>	71.6%	17.2%	4.1%	4.1%	1.8%	1.2%	3.4
<i>4 and more connected tasks</i>	42.9%	29.8%	8.9%	8.4%	2.6%	7.3%	9.0
<i>0 connectivity problems</i>	78.1%	11.5%	2.1%	2.1%	1.0%	5.2%	4.1
<i>2 connectivity problems</i>	49.5%	25.9%	8.3%	9.3%	3.2%	3.7%	7.2
<i>Poorly-connected users</i>	80.4%	9.3%	3.1%	5.2%	0.0%	2.1%	3.0
<i>Combining users</i>	50.7%	27.2%	7.3%	6.9%	2.9%	5.1%	7.2
<i>Ultra-connected users</i>	60.2%	21.1%	5.5%	7.8%	1.6%	3.9%	5.8

Source: authors’ calculations from survey data.

Before investigating the determinants of  $ARTT_i$ , we can analyze the value put on optimal MPIN connectivity on the basis of some key personal characteristics of the respondents. In line with Section 2, the more time spent in PT, the higher the degree of TBMT and/or the more connectivity problems, the greater the mean  $ARTT_i$  becomes. Respondents’ valuations are also likely to depend on the type of PT user, poorly-connected individuals asking for smaller travel time reductions (3.0 minutes) to be indifferent between current and hypothetical situations, especially compared to combining travelers (7.2 minutes).

## 4 Empirical analysis

### 4.1 Econometric strategy

The respondents’ answers to the contingent experiment inform us about the intervals which contain their “true” valuations of optimal MPIN connectivity in PT. Consequently, we have applied econometric models that accommodate “latent variables” (Long and Freese, 2001; Train, 2009).

Let us assume that traveler  $i$  initially preferred the optimal connectivity option then rejected the second offer with travel a time saving of 5 minutes. The probability that their stated  $ARTT_i$  ( $Stated_{ARTT_i}$ ) lies within the second interval in Table 5 can be formalized as:

$$Pr(Stated_{ARTT_i} = 2nd) = Pr(5 < ARTT_i < 10) \quad (10)$$

Rather than estimating the structural expression of  $ARTT_i$  (Equation (5)), we applied a reduced form approach that mirrors the main relationships between dependent and explanatory variables. Defining  $\varepsilon_i$  as a random error term that captures traveler  $i$ ’s unobserved taste for MPIN connectivity and  $Z_i$  as a vector of controls gives:

$$ARTT_i = \gamma_0 + \gamma_1 t_i + \gamma_2 C_i^c + \gamma_3 M_i + \gamma_4 Z_i + \varepsilon_i \quad (11)$$

In line with Equations (6)-(7), we expect that  $\gamma_1 > 0$ ,  $\gamma_2 < 0$  and  $\gamma_3 > 0$ .

Merging all the explanatory variables into the  $K_i$  vector, Equation (10) can be re-written as:

$$Pr(\text{Stated}_{ARTTi} = 2nd / K_i) = Pr(5 < \gamma K_i + \varepsilon_i < 10) \quad (12)$$

Once the error term has been rearranged, the choice probability related to this second valuation category is:

$$Pr(\text{Stated}_{ARTTi} = 2nd / K_i) = F_{\mu_i}(10 - \gamma K_i) - F_{\mu_i}(5 - \gamma K_i) \quad (13)$$

where  $F_{\mu_i}$  is the cumulative density function of the new error term  $\mu_i$ .

By considering all possible intervals and assuming that  $\mu_i$  are EV-Type 1 i.i.d, we estimate an ordered logit model (Long and Freese, 2001; Train, 2009).<sup>21</sup> As argued in Section 2, however, our main valuation indicator is  $RRTT_i$ , due to its direct relationship with the  $TM_i$ . In practice, we rely on ordered logit estimates to predict the distributions of  $ARTT_i$  for various travel conditions and then normalize the mean predicted  $ARTT_i$  by the PT travel time spent in these specific situations, so as to arrive at different  $RRTT_i$  and  $TM_i$  values.

#### 4.2 Results

Different econometric models have been tested. In order to estimate  $M_i$  and  $C_i^c$ , we started with the simplest divide between device-based vs. non device-based tasks, then considered variables that capture the degree of connectivity and the purposes of activities. An alternative test uses solely the typology of PT users to capture  $M_i$  and  $C_i^c$ .<sup>22</sup> In addition, Table 6 contains “fully standardized coefficients” due to variations in the measurement scales of the  $K_i$  explanatory variables, which facilitates the comparison of results because fully standardized coefficients reflect the increase in the standard deviation in  $ARTT_i$  resulting from a standard deviation increase of any member of  $K_i$  (Long and Freese, 2001).

Several conclusions emerge from our ordered logit estimates. First, the theoretical predictions discussed in Section 2 cannot be rejected:  $ARTT_i$  significantly increases with the in-vehicle travel duration (expressed as a logarithm). Second, the probabilities of choosing a large  $ARTT_i$  are higher when individuals currently perform more tasks with devices during their trips (Model 2). The travelers who already use electronic devices during their trip are those who put a higher value on the benefits of better connectivity, especially for “offline” (Model 3) or leisure activities (Model 4). In contrast, the results for non-connected tasks are never statistically significant. Put differently, individuals who currently read (printed) books or newspapers in PT may not be interested in the

21 Ordered logit models can be seen as a variant of interval data models (Train, 2009), which are often used to analyze double-bounded choice experiments (Hanemann et al., 1991; de Lapparent and Koning, 2016). We were not able to use interval data models here due to limitations in the survey design (i.e. no variation in the first bid proposed to users and the varying number of bids proposed to individuals).

22 For the sake of comparability across models, we excluded dummies related to the ownership of devices, as this information had been used to construct the typology of PT users. The availability of smartphones and tablets impacts, however, the number of device-based tasks and the incidence of connectivity problems in PT (Appendix 7.2). In addition, we used the log of the PT travel time because it significantly improves the precision of the estimates.

many possibilities offered by web-enabled devices. Third, the better the current MPIN connectivity in PT (estimated on the basis of the inverse of the number of connectivity problems), the lower the value put on optimal connectivity. More precisely, travelers who experience more problems with “offline” (Model 3) or with leisure activities (Model 4) exhibit a higher  $ARTT_i$ . Consequently, leisure activities might be those that individuals value the most during their commute, especially compared to work-related activities. With regard to the greater impact of “offline” activities, as compared to “online” ones, travelers who currently perform “offline” activities (and/or experience many problems when they do so) may imagine greater improvements in their commute experience because optimal connectivity could lead to considerable changes. “Offline” activities could then be performed entirely “online”, which would allow more flexibility in the use of the devices and require less preparation (e.g. downloading music, videos or e-books at home, or managing the memory storage of the devices). Lastly, the typology of PT users helps us understand the heterogeneity in valuations (Model 5). Combining and ultra-connected PT users put a higher value on optimal MPIN connectivity than poorly-connected travelers. If we compare the size of the parameters, combining travelers may have a higher  $ARTT_i$ , probably because they perform slightly more connected tasks in PT (Tables 4 and 9).

**Table 6 – Ordered logit estimates of  $ARTT_i$  (“fully standardized coefficients”)**

<b>Models</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>
<b>Tasks in PT without device</b>	-	-0.062	-0.059	-	-
<b>Tasks in PT with devices</b>	-	0.230***	-	-	-
<b>Tasks in PT with “offline” devices</b>	-	-	0.147***	-	-
<b>Tasks in PT with “online” devices</b>	-	-	0.116**	-	-
<b>Work tasks in PT without device</b>	-	-	-	0.007	-
<b>Leisure tasks in PT without device</b>	-	-	-	-0.060	-
<b>Work tasks in PT with devices</b>	-	-	-	0.000	-
<b>Leisure tasks in PT with devices</b>	-	-	-	0.133**	-
<b>Communication tasks in PT with devices</b>	-	-	-	0.129**	-
<b>Connectivity problems</b>	-	0.163***	-	-	-
<b>Connectivity problems with “offline” tasks</b>	-	-	0.178***	-	-
<b>Connectivity problems with “online” tasks</b>	-	-	0.125**	-	-
<b>Connectivity problems with leisure tasks</b>	-	-	-	0.167***	-
<b>Connectivity problems with communication tasks</b>	-	-	-	0.118**	-
<b>Ultra-connected travelers (vs. Poorly-connected)</b>	-	-	-	-	0.197**
<b>Combining travelers (vs. Poorly-connected)</b>	-	-	-	-	0.305***
<b>PT travel time (log)</b>	0.197***	0.173***	0.170***	0.174***	0.193***
<b>Male</b>	0.030	-0.004	-0.019	-0.010	0.019
<b>Age</b>	-0.142**	-0.002	0.012	0.002	-0.094
<b>Children</b>	0.008	-0.035	-0.031	-0.038	-0.012
<b>Part of couple</b>	-0.067	-0.032	-0.031	-0.032	-0.054
<b>Resident of the City of Paris</b>	0.010	-0.020	-0.019	-0.019	-0.008
<b>At least a Bachelor’s degree</b>	-0.025	-0.038	-0.022	-0.037	-0.040
<b>Executive</b>	0.076	0.064	0.064	0.070	0.054
<b>Motor vehicle owner</b>	0.005	-0.007	-0.005	-0.004	-0.012

<b>PT every day</b>	0.004	-0.001	0.009	-0.001	0.006
<b>Same travel zone</b>	0.059	0.081	0.083	0.083	0.072
<b>Trip seen as “wasted” time</b>	-0.189***	-0.195***	-0.196***	-0.198***	-0.174***
<b>Only subways</b>	0.062	0.082	0.083	0.079	0.061
<b>Only regional trains</b>	-0.061	-0.053	-0.053	-0.050	-0.055
<b>Only outdoor PT</b>	0.008	0.008	-0.006	-0.005	0.008
<b>Seated trip</b>	-0.018	-0.047	-0.051	-0.056	-0.023
<b>Observations</b>	501	501	501	501	501
<b>Log-Pseudolikelihood</b>	-585.349	-567.564	-564.747	-566.495	-575.972
<b>Akaike Information Criterion</b>	1212.699	1183.128	1181.494	1188.991	1197.943
<b>Bayesian Information Criterion</b>	1301.247	1284.327	1291.126	1307.056	1294.925
<b>McKelvey &amp; Zavoina Pseudo R<sup>2</sup></b>	0.095	0.173	0.183	0.180	0.145

Notes: \*\*\*:  $p < 0.01$ ; \*\*:  $p < 0.05$ ; \*:  $p < 0.1$ ; robust standard errors of parameters are available upon request.

If we examine the controls, individual heterogeneity has a very minor direct impact. This suggests that the non-representativeness of our sample with respect to the entire population of PT commuters in the Paris region (see Table 1) is not a major issue when extrapolating our results to a larger scale, as we shall do in the next Section. The only variable that has a constant (negative) effect on  $ARTT_i$  is the perception of travel time as “wasteful and unproductive”, whatever the PT mode used. The more individuals consider travel time as a waste, the more they prefer a reduction in travel time to an improvement in MPIN connectivity. Individuals who consider commuting trips as an opportunity for performing useful activities are more enthusiastic about the improvement of on-board connectivity. Yet, Model 1 suggests that older travelers put a lower value on optimal connectivity than the others. However, the corresponding parameter ceases to be significant once the variables  $C_i^c$  and  $M_i$  have been added. In fact, explanatory estimates (see Appendix 7.2) show that heterogeneity between individuals affects  $C_i^c$  and  $M_i$  much more. For instance, the number of device-based tasks is generally lower for older individuals and subway users. In contrast, it is higher for travelers who own a smartphone, who are seated during their trip, who use outdoor PT or who have children, among other factors. With regard to the number of connectivity problems, this may be influenced by the ownership of devices (positively), the travel time spent in PT (positively), the use of outdoor PT modes (negatively), individuals’ age (negatively) and the presence of children within the family (positively). Put differently, heterogeneity between individuals has an indirect impact on the values put on optimal MPIN connectivity in PT through its direct effects on  $C_i^c$  and  $M_i$ .

From an empirical point of view, the goodness-of-fit statistics in Table 6 suggest that distinguishing between connectivity problems and device-based activities across “online” vs. “offline” modes is the best way to capture variations in  $ARTT_i$ . It is worth noting, however, that Model 3 may be too complex to operationalize compared with Model 2 which also seems to be acceptable in terms of the Bayesian Information Criterion. Moreover, a Brant test confirms that the latter model is a good candidate because the “parallel regression assumption” (an important assumption in the case of ordered logit models; see Long and Freese, 2001) is not violated for  $C_i^c$  and  $M_i$  (as for Model 3). Since we consider the typology of PT users as informative, we may also consider Model 5. In this case, however, the Brant test warns us about potential model miss-specification. The parameter associated with the combining PT users is not constant across categorical outcomes, its positive impact declines for the highest intervals of  $ARTT_i$ .

We have performed additional estimates (not reported here but available upon request) to check the robustness of our main empirical findings. First, creating interactions with the PT travel time, the number of connectivity problems and the number of tasks performed with devices does not improve the results. Most of the new estimators are not statistically different from zero and the goodness-of-fit statistics do not validate these specifications. Second, the values put on optimal connectivity are not impacted by individuals' incomes. This information was accurately reported by 409 travelers during the survey. Adding this variable to the vector of controls does not modify the results. Last, due to doubts about the consistency of their SP, we removed the 21 individuals who were initially interested by connectivity improvements but consistently chose the travel time savings options. Even if the parameters for  $C_i^c$  and  $M_i$  change slightly, results obtained are very similar.

#### 4.3 Time multipliers

We shall now build on these results to estimate a value for optimal MPIN connectivity in the Paris region's PT. The calculations below are mostly based on Model 2, Table 6, while Appendix 7.3 reports the indicators found with Models 3 and 4. First, we predicted the distribution of  $ARTT_i$  by fixing the significant variables in Table 6 at their averages for different travel conditions. We then computed the mean  $RRTT_i$  by multiplying the predicted probabilities with interval-specific values and by considering the average travel time spent in PT in these circumstances. We have applied the lower bounds of the minimum and maximum intervals shown in Table 5. For instance, the "0-5 minutes" range is associated with an  $ARTT_i$  of zero. The values in Table 7 are therefore conservative compared to those in Table 5 which consider the actual travel time in PT for the "above 25 minutes" category.

Having said this, we observe that the predicted distribution of  $ARTT_i$  is very similar to that in Table 5, even if the lower categories are slightly over-represented. If we consider the entire sample, we predict a mean  $ARTT_i$  of 4.7 minutes, which implies an average  $RRTT_i$  of 12% and a mean  $TM_i$  of 0.88. In other terms, each minute spent in optimally connected PT vehicles would generate a utility cost equal to 88% of that resulting from one minute spent with current travel conditions in the Paris region's PT. Alternatively, this means that the benchmark  $VOTT$  should be reduced by 12% if MPIN connectivity in PT became optimal.

**Table 7 – Predicted time multipliers (TM) with respect to the optimal connectivity scenario**

ARTT intervals (in minutes)	<5	5-10	10-15	15-20	20-25	>25	ARTT	RRTT	TM
<i>Chosen values for <math>ARTT_i</math></i>	0.0	7.5	12.5	17.5	22.5	25.0	-	-	-
<b>Whole sample</b>	60.2%	23.6%	5.6%	5.9%	1.6%	3.2%	4.7	11.9%	0.88
<b>PT time &lt; 30 min.</b>	70.3%	18.7%	4.0%	4.0%	1.0%	2.0%	3.3	18.2%	0.82
<b>PT time &gt; 30 min.</b>	54.8%	25.8%	6.6%	7.0%	2.0%	3.9%	5.4	11.0%	0.89
<b>0-1 connected tasks</b>	72.3%	17.4%	3.6%	3.6%	0.9%	1.8%	3.0	7.7%	0.92
<b>2-4 connected tasks</b>	61.6%	23.0%	5.4%	5.6%	1.5%	3.0%	4.5	11.8%	0.88
<b>5 or more connected tasks</b>	39.8%	29.5%	9.4%	11.1%	3.3%	6.9%	7.8	19.3%	0.81
<b>0 connectivity problems</b>	76.7%	15.2%	3.0%	2.9%	0.8%	1.5%	2.6	7.6%	0.92
<b>1 connectivity problem</b>	63.4%	22.2%	5.1%	5.2%	1.4%	2.8%	4.2	10.5%	0.89
<b>2 connectivity problems</b>	48.7%	27.7%	7.7%	8.5%	2.4%	4.9%	6.3	15.5%	0.85
<b>0-1 tasks and 0 problems</b>	79.6%	13.4%	2.6%	2.5%	0.7%	1.4%	2.2	6.2%	0.94
<b>Tasks&gt;4 and 2 problems</b>	34.2%	29.8%	10.4%	13.0%	4.0%	8.6%	8.9	22.2%	0.78

<b>Poorly-connected</b>	78.7%	13.7%	2.7%	2.7%	0.7%	1.4%	2.3	6.0%	0.94
<b>Combining users</b>	51.3%	26.3%	7.2%	8.1%	2.4%	4.8%	6.0	15.2%	0.85
<b>Ultra-connected users</b>	62.7%	21.9%	5.2%	5.5%	1.5%	3.0%	4.3	11.7%	0.88

Source: authors' calculations from Models 2 and 5, Table 6.

Our estimates have confirmed that  $ARTT_i$  positively depends on the PT travel time, on the incidence of connectivity problems, as well as on the number of device-based tasks. The degree of TBMT seems to have the greatest impact. Whereas  $TM_i$  declines from 0.92 to 0.85 when the number of connectivity problems rises from 0 to 2, it ranges between 0.92 for individuals who perform no more than 1 connected task and 0.81 for “intensive” multi-taskers (who perform at least 5 activities on their devices).<sup>23</sup> By combining the two dimensions, we can identify polar cases:  $TM_i$  is equal to 0.94 for individuals who perform a limited number of device-based activities and benefit from good MPIN connectivity. In contrast, optimal connectivity is valued more highly by travelers who use their devices intensively and who experience a large number of problems ( $TM_i$  is equal to 0.78). These extreme valuations are not much different from those found when we consider the typology of PT users. Based on Model 5, Table 6, we estimate a  $TM_i$  equal to 0.85 for combining travelers, compared with 0.94 for poorly-connected individuals. The latter figures suggest that individual heterogeneity, here captured by PT user types, may have a non-negligible influence on valuation parameters.

The results in Table 7 reflect subjective values of the travel time with respect to a hypothetical situation where the MPIN connectivity in Paris PT became “optimal”. Fortunately, they can be used to assign values to more gradual improvements. Equation (14) formalizes the time multiplier to be considered if the number of connectivity problems experienced by PT users were to fall from 2 to 1 ( $TM^{2T \rightarrow 1T}$ ):

$$TM^{2T \rightarrow 1T} = \frac{\delta^{1T}}{\delta^{2T}} = \frac{\left(\frac{\delta^o}{\delta^{2T}}\right)}{\left(\frac{\delta^o}{\delta^{1T}}\right)} = \frac{TM^{2T \rightarrow o}}{TM^{1T \rightarrow o}} \quad (14)$$

where  $\delta^o$ ,  $\delta^{1T}$  and  $\delta^{2T}$  express the marginal disutility of travel time when the MPIN connectivity is optimal, characterized by 1 and by 2 connectivity problems respectively;  $TM^{1T \rightarrow o}$  and  $TM^{2T \rightarrow o}$  are the time multipliers for the two latter situations (see Table 7).

Computing these alternative time multipliers slightly changes the picture: connectivity improvements are still valued by individuals, but to a lesser degree. In fact, the  $VOTT$  would decrease by 9% if the number of connectivity problems experienced by travelers fell from 2 to 0. This difference compared with previous results is because individuals who experience any connectivity problem in the reference situation nonetheless value the optimal scenario (their  $TM_i$  is equal to 0.92). Table 8 also shows the time multipliers associated with decreases in the degree of connectivity to communication networks. In the event of travelers facing more problems when trying to use their devices in PT, the  $VOTT$  would increase by 3-9%.

**Table 8 – Time multipliers for gradual connectivity improvements**

23 The (low) time multiplier for individuals who travel less for than 30 minutes (0.82) is due to a “denominator effect”, because  $ARTT_i$  is normalized by a (low) travel time of 18.3 minutes.

<b>All connectivity problems</b>				
<i>Moving from:</i>				
<i>To:</i>		<b>0 problems</b>	<b>1 problem</b>	<b>2 problems</b>
	<b>0 problems</b>	1.00	0.97	0.91
	<b>1 problem</b>	1.03	1.00	0.94
	<b>2 problems</b>	1.09	1.06	1.00
<b>Connectivity problems with “offline” tasks</b>				
<i>Moving from:</i>				
<i>To:</i>		<b>0 problem</b>	<b>1 problem</b>	<b>2 problems</b>
	<b>0 problems</b>	1.00	0.93	0.78
	<b>1 problem</b>	1.08	1.00	0.84
	<b>2 problems</b>	1.28	1.19	1.00
<b>Connectivity problems with leisure tasks</b>				
<i>Moving from:</i>				
<i>To:</i>		<b>0 problems</b>	<b>1 problem</b>	<b>2 problems</b>
	<b>0 problems</b>	1.00	0.95	0.85
	<b>1 problem</b>	1.06	1.00	0.90
	<b>2 problems</b>	1.18	1.11	1.00

Source: authors' calculations from Tables 7 and 11.

PT users place a higher value on the optimal connectivity scenario when they experience more problems with “offline” or leisure tasks. It is therefore tempting to also compute time multipliers for gradual changes in these dimensions. Based on Table 11, Appendix 7.3, we do indeed find potentially important gains when travelers can use their devices in “offline” modes more easily (the  $TM_i$  ranges between 0.78 and 0.93) or can perform connected leisure tasks (0.85-0.95). A corollary of these higher valuations when there are fewer connectivity problems - as compared to those found without any distinction - is that improvements in “online” or in communication tasks do not really matter to users, the corresponding  $TM_i$  (not reported here) being close to unity.

Lastly, it is possible to propose parameters for when individuals perform a greater or lesser number of tasks with electronic devices during their trips. Although the positive correlation between the degree of travelers' TBMT and the number of connectivity problems (see Appendix 7.2) calls for further research, any policy that improves the quality of MPIN in PT could enhance individuals using their devices more intensively. As illustrated in Table 12, Appendix 7.3, the resulting diversity in travel time use may lead to utility gains that could be estimated by a decrease in the benchmark  $VOTT$  of between 5 and 13%.

## 5 Discussions

### 5.1 Comparison with other valuation parameters

By analyzing the SP of 501 inhabitants of the Paris region, we have demonstrated that improvements in MPIN connectivity in PT may generate non-negligible utility benefits to travelers. To what extent are the results presented above consistent with previous findings in the literature?

Even if they are not easily comparable, our results have many similarities with those reviewed in Section 2. Like Banerjee and Kanafani (2008) or Varghese and Jana (2018), we have shown that better MPIN connectivity in PT leads to a decrease in the  $VOTT$ , with more marked reductions for



individuals who spent their travel time performing leisure activities. Importantly, the drop in *VOTT* estimated here (around -10%) is close to that proposed by Kouwenhoven and de Jong (2018) in the case where Dutch PT users would have access to a computer during their trip (-5%). We also show, like Malokin et al. (2017), that this reduction is largely driven by the level of travelers' "polychronicity" (i.e. their attitude with regard to TBMT), and potentially by their age. Indeed, our results show that ultra-connected travelers, whose average age is 31 years old (66% of millennials), exhibit a greater decline in *VOTT* (-12%) than poorly-connected individuals (-6%), who are on average older (46 years old, 19% of millennials). All in all, we consider that our results concur with previous empirical findings.

It may also be interesting to compare our valuation parameters with those found for other qualitative attributes of PT in the Paris region. Based on Kroes et al. (2006), the time multipliers associated with the punctuality of regional trains range from 6 to 10, the largest losses characterizing non-commute trips with a high probability of a 10 minute delay. Even if these results must be considered cautiously<sup>24</sup>, the benefits to users from optimal MPIN connectivity are consequently moderate compared to those resulting from a policy that increased the reliability of regional rail in the Paris area. The difference is less marked for valuations of PT crowding (Kroes et al., 2013; Haywood and Koning, 2015): the time multipliers attain 1.5-1.6 when in-vehicle density in the Paris subway is high (6 passengers/m<sup>2</sup> or more), as compared to a reference situation where travelers can be seated. Considering incremental changes, Haywood and Koning (2015) show that adding 1 passenger per square meter in vehicles increases the  $TM_i$  by 0.11. Put another way, the adjustment in the benchmark *VOTT* used to take account of the utility effects of PT congestion in the Paris area is not very different from that which can be applied in order to assess the benefits users derive from improved MPIN connectivity, as we shall now demonstrate.

## 5.2 Socioeconomic appraisal

The main PT operator in the Paris region (RATP) is currently deploying 4G wireless technology over its railway network with the help of the regional PT regulator and communication services providers (see Footnote 5). Even if the purpose of this research is not to propose a comprehensive costs-benefits analysis, we can use our results to consider the socioeconomic validity of this investment program whose cost for public spending amounts to €400M.<sup>25</sup>

We postulate that 4G technology will reduce the number of connectivity problems experienced by travelers who use devices in the Paris subway. To be on the safe side, we have assumed that individuals who reported 2 connectivity problems during the survey (43% of the sample) will experience only one once 4G has been deployed, and those who reported experiencing 1 connectivity problem (38%) will no longer have any. In addition, those people who initially experienced no problems (19%) will be unaffected by the change. For the sake of simplicity, we have assumed that the total amount of time daily spent in Paris subway in 2017 (958,000 hours) is

24 According to estimates by Kroes et al. (2006), the disutility generated by a 10 minute delay when 7 out of 20 trains are delayed (i.e. an average delay of 3.5 minutes= $10 \times 7/20$ ) is equivalent to 37.2 in-vehicle minutes, which gives a time multiplier of 10.6 ( $=37.2/3.5$ ).

25 This €400M bill only takes account of public investments in antennas near the railway or subway tracks. Private firms that will deliver 4G to customers must additionally make (unknown) expenditure to connect their own networks to these antennas.

distributed in the same way as the percentage of connectivity problems within our sample.<sup>26</sup> We also base our calculations on the most simple time multipliers (that do not differentiate between connectivity problems according to the purposes of tasks or “online” vs. “offline” modes).

In order to estimate the user benefits (*UB*) resulting from improved MPIN connectivity in PT, we have started from the official *VOTT* of €11.8/hour given (CGSP, 2013) for travelers in the Paris region in 2017. We have then multiplied the total amount of time spent under different travel conditions with the *TM<sub>i</sub>*, taking account of incremental changes in the connectivity level (Table 8):

$$UB = 958000 \times 11.8 \times (0.43 \times (1 - 0.94) + 0.38 \times (1 - 0.97)) = 420524 \text{ euros/day} \quad (15)$$

If we consider 260 working days per year, we find an annual decrease in the generalized costs borne by Paris subway users of €109.3M. In addition, the Net Present Value of the €400M euros invested by the public authorities will be positive after 6 years, if we apply official French values for the social discount rate (4.5%) and the marginal opportunity cost of public funds (20%) (CGSP, 2013). As these estimates are conservative<sup>27</sup>, we can therefore conclude that deploying 4G technology in the Paris subway is a very good investment from a socioeconomic perspective. Above all, these simple calculations illustrate the operational advantages of our empirical findings.

### 5.3 Caveats and further research

This research does not claim to be the last word on the valuation of MPIN connectivity in the Paris region’s PT in relation with TBMT. Certain limitations in the survey or in the modeling framework call for further research. Moreover, several findings open the way for broader theoretical considerations.

A first issue relates to the marketing strategies of the PT operator and communications service providers once 4G has been deployed over the entire regional transport network. Offering travelers good access to 4G may be deemed a public service that should not be priced. But it could also be possible, by adopting a “premium service approach”, to restrict free-connectivity after a given length of time and then charge a fee, as is often the case in airports. Since our contingent experiment was based on trade-offs between travel times and improvements in MPIN connectivity, our results are unfortunately meaningless in this respect. Therefore, it may be useful to design a new SP study based on changes in PT fares, so as to propose a direct assessment of *VOTT*.

A second caveat comes from our working assumption that the variables that describe MPIN connectivity and TBMT are exogenous. Exploratory estimates in Appendix 7.2 in fact illustrate that complex interdependencies between the two dimensions may be at work. As a consequence, further research must be conducted to properly understand the main relationships between the quality of MPIN connectivity in PT, the degree of TBMT and some key personal characteristics. From an

26 The 958,000 hour figure has been arrived at by considering subway traffic of 7.817M passenger-kilometers in 2017 (OMNIL, 2018) and by applying the same calculation rule as in Footnote 4. Assuming that subway travel time is distributed in the same way as the number of connectivity problems provides conservative estimates because of the positive relationship between the two variables (Appendix 7.2).

27 First, travelers who experience more connectivity problems may spend more time in the subway. Second, the benefits resulting from 4G will also be felt by users of the regional trains. Third, subway ridership will grow during the years to come. Fourth, those users who reported experiencing no connectivity problems during the survey could also value improvements in MPIN connectivity. Alternatively, we assume that 4G will correspond to the optimal connectivity scenario, and have thus considered an average *TM<sub>i</sub>* of 0.88. In this case, the benefits for subway users amount to €353M per year.

empirical point of view, “structural equations modeling” (Eboli and Mazzulla, 2012) or “hybrid discrete choice models” (Ben-Akiva et al., 2002; Bouscasse and de Lapparent, 2019) may suit this purpose.

The third limit is linked to survey scope and method. The data analyzed in this paper only relate to PT travel pass subscribers in the Paris region. It would be worthwhile to compare these results with other data that include car or bicycle users in order to identify the potential for modal shift resulting from ICT-based activities, and not only at the urban scale. To do so, we could start from the “joint analysis” (Pons, 2011; Bouscasse, 2017) where the set of choices proposed to individuals provides different alternatives, in terms of travel attributes (prices, travel times, seat conditions, MPIN connectivity, availability of devices), as well as mode choices.

Moreover, our typology of PT users has allowed us to identify contrasted attitudes and practices in the use of connected devices in PT. The typology captures the strong interactions between subjectivity, reported practices and socio-economic background. These differences in the use of connected devices in PT seem strongly correlated with the differences observed in daily life (Adoue, 2016). Can reluctance to perform connected activities while travelling be explained by a greater preference for non-connected activities, or simply by a lack of personal skills with ICT devices? Then, will these differences remain the same or lessen with the growing adoption of ICT devices and with generational changes? Perhaps the connectivity expectations of PT users exceed what they really need in order to perform online activities, leading, for example, business travelers to compensate for temporary poor connectivity by conducting offline activities. The complex relationship between connectivity and onboard activities could be more thoroughly investigated. New studies, e.g. based on sociological approaches, may help us better understand the heterogeneity of preferences in travel time uses and its consequences on the value of travel time.

Lastly, the use of connected devices to perform activities may not, in the future, be confined to PT users. Car drivers are already using smartphones for TBMT during their daily commutes (Licoppe and Figeac, 2017). The current transformations in the automotive industry such as the development of connected and autonomous cars seem to be heading towards the development of vehicles that allow motorists to perform more activities on the move. Indeed, one of the main arguments for the promotion of autonomous cars is that they will free up travelers’ time, by allowing them to perform many (connected or not connected) activities during their trips. This better use of travel time may foster social acceptance of autonomous cars (Cygansky et alii., 2015). Hence, we believe that further research has to take into account the role of connected devices in travel time valuation, regardless of the transportation mode.

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## 7 Appendices

### 7.1 Additional summary statistics

**Table 9 – Characteristics of the types of PT user**

<b>Variables</b>	<b>Poorly-connected</b>	<b>Combining</b>	<b>Ultra-connected</b>
<b>Male (dummy)</b>	0.24	0.32	0.38
<b>Age (years)</b>	46.1	38.4	31.2
<b>Live in City of Paris (dummy)</b>	0.16	0.22	0.17
<b>At least a Bachelor's degree (dummy)</b>	0.34	0.49	0.41
<b>Executives (dummy)</b>	0.25	0.37	0.30
<b>Live as part of a couple (dummy)</b>	0.91	0.86	0.84
<b>Have children (dummy)</b>	0.34	0.36	0.28
<b>Public transport travel time (minutes)</b>	39.9	39.8	37.0
<b>Door-to-door travel time (minutes)</b>	54.5	54.2	50.1
<b>Travel time seen as "wasted" time (dummy)</b>	0.68	0.63	0.71
<b>Only subways (dummy)</b>	0.14	0.18	0.16
<b>Only regional trains (dummy)</b>	0.20	0.20	0.16
<b>Only outdoor public transport (dummy)</b>	0.16	0.12	0.24
<b>Seated during the main trip (dummy)</b>	0.41	0.44	0.44
<b>Daily use of public transport (dummy)</b>	0.95	0.95	0.91
<b>Trip within the same travel zone (dummy)</b>	0.40	0.34	0.45
<b>Own a motor vehicle (dummy)</b>	0.61	0.77	0.73
<b>Activities in PT with "offline" device</b>	0.32	1.03	1.09
<b>Activities in PT with "online" device</b>	0.65	2.49	2.31
<b>Work activities in PT with devices</b>	0.01	0.18	0.16
<b>Work activities in PT without device</b>	0.07	0.13	0.06
<b>Leisure activities in PT with devices</b>	0.45	1.46	1.46
<b>Leisure activities in PT without device</b>	1.05	1.16	0.29
<b>Communication activities in PT with device</b>	0.51	1.88	1.79
<b>Connectivity problems in PT with "offline" activities</b>	0.05	0.24	0.37
<b>Connectivity problems in PT with "online" activities</b>	0.80	1.10	0.94
<b>Connectivity problems in PT with communication activities</b>	0.68	0.72	0.70
<b>Connectivity problems in PT with leisure activities</b>	0.18	0.63	0.61

Source: authors' calculations from survey data.

7.2 Exploratory estimates

Table 10 – Ordered logit estimates of  $M_i$  and  $C_i^c$  (501 observations)

Number of device-based tasks:					
Dependant variables:	All	“Offline”	“Online”	Leisure	Communication
Problems : All	0.458***	-	-	-	-
Problems : “Offline”	-	0.340***	-	-	-
Problems : “Online”	-	-	0.184	-	-
Problems : Leisure	-	-	-	0.739***	-
Problems : Communic.	-	-	-	-	-0.019
Significant controls (at 10%):	Smart. (+) Age (-) Child (+) Sub. (-) Out. (+) WT (-) Seat (+)	Smart. (+) Tab (+) PT time (+) Age (-) SZ (-) WT (-) Seat (+)	Smart. (+) Age (-) Child (+) Coup. (-) Mot. (+) Bach. (+) PTED (+) Sub. (-) Out. (+) Seat (+)	Smart. (+) Age (-) Sub. (-) Seat (+) SZ (-)	Smart. (+) Age (-) Coup. (-) Child (+) Mot. (+) Bach. (+) Seat (+) PTED (+)
Log-Pseudolikelihood	-985.87	-567.74	-846.91	-674.24	-703.18
McKelvey & Zavoina Pseudo R <sup>2</sup>	0.341	0.269	0.295	0.287	0.294
Number of connectivity problems:					
Dependant variables:	All	“Offline”	“Online”	Leisure	Communication
Device-based tasks: All	0.152***	-	-	-	-
Device-based tasks: “Offline”	-	0.205*	-	-	-
Device-based tasks: “Online”	-	-	0.069	-	-
Device-based tasks: Leisure	-	-	-	0.388***	-
Device-based tasks: Communic.	-	-	-	-	-0.016
Significant controls (at 10%):	Smart. (+) Tab. (+) Age (-) PT time (+) Child (+) Exec. (+) Out. (-)	Smart. (+) Tab. (+) Male (+) Age (-)	PT time (+) Age (-) Child (+) Paris (+) SZ (-) Out. (-)	Smart. (+) Child (+) Exec. (+) Sub. (+)	Age (-) Out. (-) Seat (-) SZ (-)
Log-Pseudolikelihood	-476.22	-260.48	-501.06	-398.71	-466.61
McKelvey & Zavoina Pseudo R <sup>2</sup>	0.197	0.375	0.147	0.234	0.122

Notes: \*\*\*: p<0.01; \*\*: p<0.05; \*: p<0.1; robust standard-errors of parameters and estimates for control variables are available upon request; “Smart.” for smartphones, “Tab.” for tablets, “Sub.” for only subways, “Out.” for only outdoor modes, “WT” for trip as wasted time, “SZ” for same travel zone, “Mot.” for ownership of motorized vehicles, “Bach.” for at least a Bachelor’s degree, “PTED” for daily PT use, “Coup.” for live as part of a couple, “Exec.” for executives.

7.3 Alternative valuation parameters

**Table 11 – Values put on the optimal connectivity scenario for “offline” (vs. “online”) activities and for leisure (vs. communication) tasks**

Scenarios	ART T	RRTT	TM	Scenarios	ART T	RRTT	TM
<b>0 “offline” task (Low)</b>	3.1	8.2%	0.92	<b>0 leisure task (Low)</b>	3.1	8.1%	0.92
<b>1 “offline” task (Medium)</b>	4.9	12.7%	0.87	<b>1-2 leisure tasks (Medium)</b>	4.9	12.5%	0.87
<b>2 or more “offline” tasks (High)</b>	7.9	18.5%	0.82	<b>3 or more leisure tasks (High)</b>	9.0	23.2%	0.77
<b>0 “offline” problems</b>	4.0	10.4%	0.90	<b>0 leisure problems</b>	3.6	9.3%	0.91
<b>1 “offline” problem</b>	6.8	16.9%	0.83	<b>1 leisure problem</b>	5.9	14.3%	0.86
<b>2 “offline” problems</b>	9.8	30.3%	0.70	<b>2 leisure problems</b>	7.5	22.9%	0.77
<b>0-1 “online” task ( Low)</b>	3.4	8.7%	0.91	<b>0 communication tasks (Low)</b>	3.2	7.6%	0.92
<b>2-3 “online” tasks (Medium)</b>	4.9	12.7%	0.87	<b>1-2 communication tasks (Medium)</b>	4.4	12.0%	0.88
<b>4 or more “online” tasks (High)</b>	7.1	18.5%	0.82	<b>3 or more communication tasks (High)</b>	7.1	17.6%	0.82
<b>0 “online” problems</b>	3.6	10.4%	0.90	<b>0 communication problems</b>	4.0	11.6%	0.88
<b>1 “online” problem</b>	4.8	11.5%	0.88	<b>1 communication problem</b>	5.1	11.9%	0.88
<b>2 “online” problems</b>	5.6	13.9%	0.86	<b>2 communication problems</b>	4.2	10.8%	0.89

Source: authors’ calculations from Models 3 and 4, Table 6.

**Table 12 – Time multipliers for varying levels of TBMT**

<b>All device-based tasks</b>					
<i>Moving from:</i>					
<i>To:</i>		<b>Low: 0-1 task</b>	<b>Medium: 2-4 tasks</b>	<b>High : 5 or more tasks</b>	
		<b>Low: 0-1 task</b>	1.00	1.05	1.15
		<b>Medium: 2-4 tasks</b>	0.95	1.00	1.09
		<b>High: 5 or more tasks</b>	0.87	0.91	1.00
<b>“Offline” device-based tasks</b>					
<i>Moving from:</i>					
<i>To:</i>		<b>Low: 0 task</b>	<b>Medium: 1 task</b>	<b>High : 2 or more tasks</b>	
		<b>Low: 0 task</b>	1.00	1.05	1.13
		<b>Medium: 1 task</b>	0.95	1.00	1.07
		<b>High: 2 or more tasks</b>	0.89	0.93	1.00
<b>Leisure device-based tasks</b>					
<i>Moving from:</i>					
<i>To:</i>		<b>Low: 0 task</b>	<b>Medium: 1-2 tasks</b>	<b>High : 3 or more tasks</b>	
		<b>Low: 0 task</b>	1.00	1.05	1.20
		<b>Medium: 1-2 tasks</b>	0.95	1.00	1.14
		<b>High: 3 or more tasks</b>	0.84	0.88	1.00

Source: authors’ calculations from Tables 7 and 11.