Transport Policy 136 (2023) 126–136

Contents lists available at ScienceDirect

Transport Policy

journal homepage: www.elsevier.com/locate/tranpol

The income elasticity of the value of travel time savings: A meta-analysis

Jawaher Binsuwadan [a,b,*], Mark Wardman [a], Gerard de Jong [a,c], Richard Batley [a], Phill Wheat [a]

[a] Institute for Transport Studies, University of Leeds, Leeds, LS2 9JT, United Kingdom
[b] Department of Economics, Princess Nourah Bint Abdulrahman University, Riyadh, PO Box 84428, Saudi Arabia
[c] Significance, Grote Marktstraat 47, 2511 BH, The Hague, the Netherlands

ARTICLE INFO

Keywords:
Income elasticity
Meta-analysis
Values of travel time savings
Project appraisal
Cross-sectional elasticity

ABSTRACT

The value of travel time savings (VTTS) is an important concept used in cost-benefit analyses for project appraisals and demand modelling in the transport sector. The relationship between the VTTS and income is particularly important since it underpins how official VTTS recommendations are uplifted over time as incomes grow. The income elasticity of VTTS has been investigated in many empirical studies, exhibiting considerable variation across them. Notably, repeat studies tend to find the lowest implied income effects and meta-analyses the largest income elasticities, with those obtained from cross-sectional inter-personal comparisons somewhere between. This paper aims to explain the VTTS variation in terms of an individual's or household's income level by using the meta-analysis technique. The analysis covers 268 income elasticities of the VTTS extracted from 49 studies conducted from 1968 to 2019 in countries across the globe. The meta-analysis method determines the factors that influence these income elasticity variations. The results of the meta-model highlight that the variation of the income elasticity is explained by several factors, including income levels, the transport mode, personal or household income, inter-temporal or cross-sectional elasticity, journey purpose and year of the survey, shedding light on how the VTTS income elasticity varies across different sources.

1. Introduction

The value of travel time savings (VTTS) is an important concept used in travel demand modelling and cost–benefit analysis of transport projects (Mackie et al., 2001; Gunn and Sillaparcharn, 2007). It plays a key role in policy and investment decision-making, since time savings can account for up to 80% of the estimated benefits of road schemes (Mackie et al., 2001). In addition, VTTS helps to explain travel behaviour as an explanatory variable in transport modelling and demand forecasting – especially in contexts where there is interest in how the time savings achieved through new infrastructure may influence travellers' decisions of whether, when and how to travel (Hensher, 2001; Shires and De Jong, 2009).

There are two dimensions of variability in VTTS that are considered in the literature and require explanation. The first is how VTTS behaves over time in representing economic efficiency, through cost–benefit analysis of the absolute and relative Value for Money (VfM) of alternative long-term investments in transport infrastructure (Waters, 1994; Small, 2012). In the UK context for example, 60 years is the standard duration for appraising a road scheme considering costs and benefits, and the current approach is to hold VTTS growth constant in the long-term according to the OBR forecast of real GDP per capita growth (Department For Transport, 2018; Rich and Vandet, 2019). Effectively, this means the use of an inter-temporal real income elasticity of the VTTS of 1. Some other countries (e.g. The Netherlands and France) recommend a lower inter-temporal income elasticity of the VTTS for use in cost-benefit analysis of infrastructure/transport projects, which can be as low as 0.5. Whether the inter-temporal income elasticity of the VTTS is 1, 0.5 or close to 0 is an issue of considerable practical importance.

As mentioned above, travel time benefits are often the main benefit component in the cost-benefit analysis of infrastructure projects (Metz, 2008, 2021). These benefits usually arise in the future (e.g. between a project opening ten years from now and 60 years ahead as the end of the appraisal period). Therefore, the VTTS to be used to monetise these benefits will refer to years in the future. The standard method in most countries to derive the VTTS for future years is to start from the VTTS from a base year (that could be based on Stated Preference surveys, possibly also using some expansion to the national totals), and to let it grow over time at a speed determined by the multiplication of the real

* Corresponding author. Department of Economics, Princess Nourah bint Abdulrahman University, Riyadh PO Box 84428, Saudi Arabia.
E-mail addresses: jabinswaidan@pnu.edu.sa (J. Binsuwadan), M.R.Wardman@its.leeds.ac.uk (M. Wardman), G.C.Dejong@its.leeds.ac.uk (G. de Jong), R.P.Batley@its.leeds.ac.uk (R. Batley), p.e.wheat@its.leeds.ac.uk (P. Wheat).

https://doi.org/10.1016/j.tranpol.2023.03.013
Received 6 September 2022; Received in revised form 14 March 2023; Accepted 17 March 2023
Available online 31 March 2023

GDP per capita growth and the inter-temporal real GDP per capita elasticity of the VTTS. Especially with substantial income growth and a high elasticity value, the VTTS can grow fast over time and with it the travel time benefits of a project. Another implication is that in the future, the preference for faster modes relative to slower modes will increase (van Goeverden, 2022). The choice of the elasticity value that should be used here is often not left to those proposing or appraising the project, but is fixed at a single value for the entire nation.

The second is cross-sectional variation in VTTS across different contexts, which gives rise to variations according to important factors such as user type, journey purposes and transport modes (Börjesson and Eliasson, 2018). Therefore, explaining the two dimensions of variations of VTTS – temporal and cross-sectional – is important to obtain an efficient allocation of resources for transport projects. As VTTS is expressed essentially as the ratio between the marginal utilities MU of travel time and money (DeSerpa, 1971), the VTTS will vary with income according to its impact on these marginal utilities.

A dependence of VTTS on income has long been present in the literature Thomas and Thompson (1970) and Waters (1994) testifies to numerous studies prior to the 1990s. Indeed, in the earliest studies and for some years it was customary to express the VTTS as a proportion of the wage rate (Hensher, 2019).[1] It can be expected that the connection between income and VTTS is essentially one for empirical determination and it is considered to be the most important factor causing variations in VTTS (Gunn, 2001). That relationship is often expressed by the elasticity of VTTS with respect to income (Axhausen et al., 2008). The income elasticity of VTTS is defined as the proportionate change in VTTS with respect to a proportionate change in income level.[2] This paper addresses how study-specific characteristics and within-study differences can explain the observed variations in the income elasticity of VTTS. This is in contrast to previous VTTS meta-analyses, which used a country's gross domestic product (GDP) as an income variable to explain the variations in VTTS (Wardman et al., 2016). Usually, GDP is used as a proxy of income measure as it is available for all countries; however, using gross household income or net income could be more appropriate and is used here.

Adopting infrastructure project appraisal practice that focuses on monetised travel time gains is discussed in the literature (Metz, 2008; Martens and Di Ciommo, 2017). Furthermore, different studies have proposed alternative methods that are thought to better reflect the changes in spatial patterns and social equity considerations (Wang and Levinson, 2022; Van Geenhuizen et al., 2016). Thus, higher VTTS are used to justify transport investments that matter with increased travel speeds. This can lead to favour faster modes and highway expansions over slower modes and different public transport improvements (Tranter, 2010; Litman, 2021, 2021van Goeverden, 2022). However, most project appraisal systems used in practice by national governments or international organisations still use monetised travel time gains, for which the future values are determined on the basis of the income elasticity of the VTTS. Therefore, it is very important to study this relationship between income and VTTS.

The use of meta-analysis technique in the behavioural and social sciences emerged in the 1970s. Glass (1976) was the first to employ the term 'meta-analysis', which subsequently became a powerful tool in social sciences research. Researchers from different fields have shown an increased interest in applying meta-analysis techniques, since it offers a means of assimilating and reviewing the quantitative results of multiple empirical studies on a common topic (Wampold et al., 2000; Cleophas and Zwinderman, 2007). Meta-analysis method provides important statistical results that are more robust than those of individual primary studies, due to the aggregation of results over multiple such studies. Moreover, this form of analysis increases precision and limits bias, thus improving the consistency of the results and conclusions (Chalmers and Altman, 1997). However, the results of a meta-analysis can still be affected by the precision and quality of the individual studies, potentially leading to unreliable results. Indeed, critics of meta-analysis highlight the risks associated with data quality and lack of consistency across individual studies, and these critiques should be borne in mind when collecting data and adding quantifying moderator variables to investigate variations (Ioannidis and Lau, 1999; Button, 2019).

The present study systematically reviews the estimates of the income elasticity of VTTS. This study contributes to the existing literature by performing the first meta-analysis examining how reported income elasticities of VTTS vary across studies and countries as the main object of interest, which contrasts with previous VTTS meta-analyses which have focussed on variations in the values themselves. To achieve this aim, a meta-analysis framework is used to explain variations across studies. The present meta-analysis includes studies from around the world and applies a statistical analysis to pool the values. In addition, the heterogeneity of the dataset has been considered, as several studies from different countries are captured within the modelling.

The remainder of the paper proceeds as follows: Section 2 briefly discusses the income elasticity of the VTTS. Section 3 provides a brief review of the meta-analysis method in the transport sector. Section 4 illustrates the dataset and search approach, while section 5 introduces the meta-model. In section 6, the estimation results are stated and interpreted with implications. Section 7 provides a conclusion and suggestions for future work.

2. Income elasticity of VTTS

The VTTS formulation emanates from time allocation theory, which considers time as good with limited availability for individuals (Becker, 1965; Johnson, 1966; Oort, 1969; DeSerpa, 1971). This time budget limitation is considered in the context of a utility maximisation problem, where different individuals experience different utility levels and face different constraints (Jara-Díaz, 2000). From theoretical and practical perspectives, there is a link between income and the VTTS – with the expectation of a positive relationship of varying magnitudes (Waters, 1994). Some studies have found that VTTS increases in constant proportion to the income level (Quarmby, 1967)[3]; other studies have found that rising income levels increase the VTTS at a rate less than unity (McDonald, 1975; MVA, 1987); still other studies have shown VTTS to increase more than proportionately with income (Beesley, 1965). In short, the relationship is complex, and the magnitude of change may depend on the level of income itself (Thomas and Thompson, 1970).

In the course of the two most recent UK national studies of VTTS, Mackie et al. (2003) and Batley et al. (2015) estimated the income elasticity of VTTS, using Stated Preference (SP) data on trade-offs between travel time and cost collected from a large sample of travellers engaged in a range of journeys across different modes and purposes at a given point of time. Elasticity is a useful concept to understand how an individual's valuation might react to changes in constraints, such as income. Individuals may change their travel choices when their incomes increase, for example by choosing a more expensive mode or route to save time. This relationship between income and VTTS can be expressed by the elasticity of VTTS with respect to income[4] (Axhausen et al., 2008), thus:

$$\mathscr{E}_{\mathbf{VTTS,Y}} = \frac{\partial \mathbf{VTTS}}{\partial \mathbf{Y}} \cdot \frac{\mathbf{Y}}{\mathbf{VTTS}} \tag{1}$$

[1] The VTTS recommended for the appraisal of freight travel and for briefcase business travel is typically directly related to the wage rate, the so called Cost Savings Approach, thereby implying a VTTS income elasticity of one.

[2] Strictly speaking, this definition refers to an 'arc' elasticity.

[3] This corroborates appraisal practice in the UK and some other countries.

[4] Strictly speaking, this definition refers to a 'point' elasticity.

where VTTS and Y are the value of travel time savings and income, respectively. Estimates of the income elasticity of VTTS from SP studies can be obtained through two discrete choice modelling methods: either the marginal utility based method, where the model is estimated in 'utility space', or the marginal rate of substitution based approach, where the model is estimated in 'willingness to pay (WTP) space' (Train and Weeks, 2005; Ojeda-Cabral et al., 2016). Previous studies have mainly used the utility space to estimate VTTS by means of the ratio of the time and cost coefficients (e.g. Mackie et al., 2003); thus, income elasticity was estimated by variation across different levels of income. In contrast, newer studies (e.g. Batley et al., 2015) have used WTP space, which directly estimates VTTS without the separate time and cost coefficients. Therefore, a question of interest is whether the income elasticity derived from these two methods differs to any extent, all else equal.

Almost all studies relating to the impact of income on VTTS are cross-sectional, derived from discrete choice models by calculating VTTS for different income levels. Such models are based on SP or Revealed Preference (RP) data of time vs. money trade-offs (Fosgerau, 2005). For example, the earliest British studies on the national value of time (MVA, 1987, Accent and Group, 1999) identified a clear and strong correlation between income and VTTS, with income elasticity of VTTS range between 0.35 and 0.65 based on different journey purposes. Similarly, the latest British national study found a significant positive relationship between VTTS and income in different transport modes and journey purposes, with 0.02 income elasticity for bus/commuting and 0.68 income elasticity for car/leisure. In the most recent Danish national study, a positive relationship between income and VTTS was found, with a cross-sectional income elasticity of between 0.3 and 1 by different mode and journey purpose (Rich and Vandet, 2019). It is questionable however whether cross-sectional elasticities are a reasonable proxy for inter-temporal elasticities, since quite different factors could be driving the variations observed. In order to shed light on this question, there is interest in estimating inter-temporal elasticity by either repeated SP studies or meta-analysis since such analyses potentially offer a means of dissecting cross-sectional and temporal dimensions.

In most repeated SP studies, involving comparisons of income elasticity for different years in the same country, the income elasticity has been found to be positive but less than proportional (Börjesson et al., 2012). However, negative income elasticities have been observed in some studies for some journey purposes, such as leisure. This decreasing trend might be explained by the use of new technologies that affect the marginal disutility of travel time and cost (Gunn, 2001; Wardman, 2001a). As efficiency, comfort and facilities increase, the marginal disutility of time will decrease over time, all else being equal. Another method that can be used to obtain inter-temporal income elasticity is meta-analysis, which considers the large amount of empirical evidence on the income elasticity of VTTS in order to develop a quantitative relationship between VTTS and various explanatory factors. The inter-temporal income elasticity of VTTS based on the meta-analysis method also suggests a positive link between VTTS and income (Abrantes and Wardman, 2011; Shires and De Jong, 2009; Wardman et al., 2016).

Given these patterns of variation, a meta-analysis method could help to identify the sources of such variation, such as the postulated interrelationship with income. Evidence from cross-sectional studies usually shows income elasticities to be lower than inter-temporal elasticities, which are reported in meta-analyses and repeated SP studies. Cross-sectional income elasticities range from 0.3 to 0.7 (Börjesson and Eliasson, 2014), while inter-temporal elasticities range from 0.5 to almost unity (Abrantes and Wardman, 2011; Wardman et al., 2016). Therefore, almost all methods used to estimate income elasticity have a clear tendency toward positive income elasticity of VTTS; however, the magnitude of this elasticity varies and may be affected by the definition of income used to estimate the VTTS, transport mode, journey purpose and other factors.

In addition, there are factors that drive the differences between the cross-sectional and inter-temporal income elasticity of VTTS. The first factor is that an increasing VTTS over time might occur due to income changes and other associated factors, such as changes in individuals' preferences, technological advances, travel conditions and quality (Laird et al., 2013). Another factor could be that cross-sectional and inter-temporal studies show differences in the measures of income employed (e.g. household or personal income, gross or net), and these measures may be subject to different degrees of error (Fosgerau, 2005). The final factor is that because VTTS naturally varies across income groups, the cross-sectional income elasticity is not constant (Börjesson et al., 2012). Therefore, the relationship between VTTS and income is potentially complex, and may be subject to multiple sources of variation both temporally and cross-sectionally.

3. Meta-analysis methodology

Meta-analysis is the examination of empirical results drawn from independent studies on the same subject in order to identify the factors that influence those results and to quantify the impacts of those influential factors. The introduction points out that researchers in a wide range of disciplines have now made use of the technique, enabled in an era when it is common that numerous studies have investigated the same issues. The application of the meta-analysis method in transport research first appeared in the mid-1990s, and its attractions and limitations in this context have been rehearsed elsewhere (Button, 1995, 2019; Elvik, 2005; Wardman, 2012). In summary, its attractions are that it can quantify impacts that can only be attained by inter-study comparisons, such as inter-temporal, spatial and methodological, being more robust to the confounding effects that can afflict traditional literature reviews and providing estimates of parameters of interest where none otherwise exist or to benchmark emerging evidence. Whilst it cannot provide some of the detailed insights of primary research, it provides a significant complement to it.

Meta-analysis is now a generally accepted research tool with widespread application. Wardman (2012) points out that it has been used extensively in the transport context to examine a wide range of parameters, for both passenger and freight transport, including valuations of travel time savings and travel time variability, traffic related noise valuations, demand elasticities, cross-elasticities between modes, and more general behavioural issues. This application is original since it is concerned not with VTTS per se, which has been addressed in a number of other meta-analyses, but with change in VTTS in the form of its income elasticity, which has not been the subject of meta-analysis. The income elasticity of the VTTS has been estimated in many studies, and variation is apparent across these studies, whereupon the opportunity for meta-analysis arises. The coverage is inevitably international, but because we are dealing with variations in VTTS, in terms of dimensionless elasticities, we do not face the challenges involved in international VTTS comparisons of allowing for different currencies, price levels and purchasing power.

4. Data assembly and characteristics

4.1. Identification of evidence

An electronic search was used to identify relevant studies using various keywords and search engines, supplemented with the examination of specialist databases in transport studies[5] and conference

[5] TRID is the Transport Research International Documentation (https://trid.trb.org). It is "an integrated database that combines the records from TRB's Transportation Research Information Services Database and the OECD's Joint Transport Research Centre's International Transport Research Documentation Database".

websites, and contacting academics and consultants known to be active in this area. This process yielded 268 income elasticities gathered from 49 studies published between 1968 and 2019. Income elasticities less than zero, of which 12 were uncovered, were not included in the assembled data set.

To place this sample in some context, the first meta-analysis of VTTS (Wardman, 1998) covered 444 values from 105 studies, increasing to 560 valuations from 139 studies in Wardman (2001) and 1001 from 220 studies in Abrantes and Wardman (2011), all of which were based on U.K. evidence. Extending to the rest of Europe, Wardman et al. (2016) covered 1839 valuations drawn from 385 studies, although the prior international studies of Zamparini and Reggiani (2007)and Shires and de Jong (2009) respectively covered 90 valuations from 53 studies and 1299 valuations from 77 studies. However, these meta-analyses were concerned with explaining VTTS variation and none addressed the second order issue of income elasticities of VTTS. Bearing in mind we are here dealing with variations in VTTS due to a single variable, the sample obtained here is quite respectable.

Multiple observations are drawn from studies if they provide independent insights, such as variations in the income elasticity according to factors, such as journey purpose, mode, distance and method. Table 1 presents the number of observations per study. Two-thirds of studies yield 5 or less elasticities, although these comprise only around a third of the total number of elasticities. The three studies with over 15 elasticities provide 20% of the data.

The dataset was compiled from various sources. Of the 268 elasticities, journal papers provided 24% from 19 studies with conference papers, published reports and unpublished reports respectively providing 30%, 24% and 22% of the elasticities from 10, 11 and 9 studies. Table 2 illustrates the distribution of observations and studies across countries. The country that has provided the most evidence is the UK,[6] the Netherlands, Norway and Sweden. These countries have a long tradition of evidence based transport appraisal and notably have conducted multiple national VTTS studies.

4.2. Descriptive statistics

The mean and median income elasticities were 0.34 and 0.23 respectively with a standard deviation of 0.31 and a maximum of 1.96. The positive skew is apparent in the frequency distribution presented in Fig. 1. It is very clear that the estimated income elasticities exhibit considerable variation but generally fall well short of the practice of increasing VTTS in line with income that is applied in administrations that recommend VTTS for transport appraisal and forecasting.

The descriptive statistics presented in Table 3 serve two purposes. First, they relate to the set of variables and the categories within them about which information was collected to be used as potential explanatory factors in the meta-model. Some of these variables provide methodological insights whilst others indicate structural impacts or are useful in the interpretation of income elasticities and their use in appraisal. Second, they indicate the sample sizes relating to the categories of each variable and inform the extent of income elasticity variation. These are straightforward one-dimensional segmentations and therefore could be influenced by confounding factors which the subsequent meta-analysis aims to overcome. Nonetheless, they provide a flavour of the variation in income elasticities.

Journey purpose is a key explanatory factor in behavioural analysis and segmenting variables in forecasting and appraisal. The largest category is, unsurprisingly, commuting which forms 39% of the total whilst in just over a quarter of cases no distinction was made by journey purpose. Transport mode is another key variable and it is not surprising that car has the largest number of observations with 42%, followed by all modes category that covers income elasticities generally for public transport modes with 23%.

Income elasticities have been sourced from cross-sectional variations in VTTS across different income levels and inter-temporal variations from repeat SP studies. The former provides the vast majority of the evidence at 92% but the income elasticity is on average 42% lower which is one of the largest variations in Table 3. We have distinguished between income specified as household or personal. Two thirds of the evidence relate to a household based definition of income and the mean income elasticity is around 20% lower.

We now turn to variables of a more methodological nature. Unsurprisingly, the vast majority of the income elasticities were estimated to SP data. These are on average 27% lower than those obtained from RP data. Nor is it surprising to find that the abstract choice context is not only the largest category but provides almost two thirds of the evidence. The most common experimental design underpinning the SP exercises is orthogonal, which forms almost half of the evidence, whilst a Bradley

Table 1
Distribution of income elasticities per study.

Elasticities per study	Cases	Total elasticities	Elasticities per study	Cases	Total elasticities
1	4 (8%)	4 (1%)	5	5 (10%)	25 (9%)
2	11 (23%)	22 (8%)	6–10	9 (19%)	61 (23%)
3	5 (10%)	15 (6%)	11–15	5 (10%)	59 (22%)
4	7 (14%)	28 (11%)	16–20	3 (6%)	54 (20%)

Table 2
Income elasticity and number of studies by country.

Countries	Number of Studies	Number of income elasticities	Countries	Number of Studies	Number of income elasticities
Australia	4	19	New Zealand	1	6
Bangladesh	1	3	Norway	3	36
Chile	3	5	Singapore	1	5
Denmark	3	11	Spain	1	6
Finland	1	3	Sweden	5	24
Germany	1	4	Switzerland	3	7
India	1	3	UK	14	85
Netherlands	4	36	USA	3	15

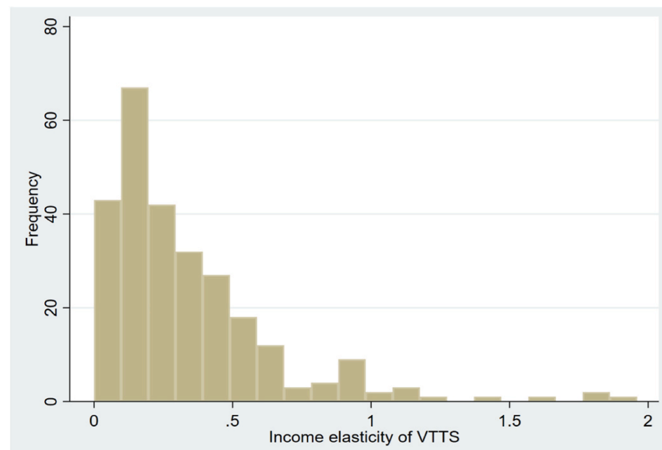

Fig. 1. Frequency distribution of income elasticities.

[6] We are naturally more aware of UK studies, and particularly the 'grey literature', which will have contributed to the relatively large amount of UK evidence.

Table 3
Explanatory variable and summary statistics.

Variable	Categories	Obs, (Mean), [Std Dev], {Min: Max}
Elasticity Specification	Point Elasticity	108, (0.399), [0.298], {0.00:1.82}
	Arc Elasticity	160, (0.298), [0.321], {0.01:1.96}
Journey purpose	Business	45, (0.379), [0.282], {0.01:1.17}
	Commuter	105, (0.281), [0.264], {0.00:1.78}
	Leisure	45, (0.370), [0.327], {0.05:1.58}
	No distinction	73, (0.377), [0.379], {0.01:1.96}
Transport mode	Car	112, (0.366), [0.307], {0.00:1.82}
	Train	41, (0.273), [0.185], {0.01:0.94}
	Bus	45, (0.290), [0.326], {0.02:1.96}
	Air	8, (0.163), [0.097], {0.01:0.30}
	All modes	62, (0.391), [0.385], {0.01:1.78}
Distance	<40 km	25, (0.486), [0.490], {0.02:1.96}
	40–100 km	39, (0.325), [0.203], {0.01:0.89}
	>100 km	45, (0.326), [0.360], {0.01:1.82}
	Missing	159, (0.322), [0.284], {0.01:1.78}
Spatial context	Inter-urban	134, (0.315), [0.285], {0.00:1.96}
	Urban	68, (0.403), [0.341], {0.04:1.78}
	All trips	66, (0.320), [0.337], {0.01:1.82}
Year of data collection	Up to 1990	57, (0.208), [0.204], {0.01:1.17}
	1991–2000	89, (0.393), [0.375], {0.00:1.96}
	2001–2010	72, (0.379), [0.346], {0.01:1.82}
	2011–2019	50, (0.333), [0.194], {0.02:0.78}
Annual Income level	≤$20,000	24, (0.507), [0.504], {0.02:1.96}
	$20,001–40,000	73, (0.348), [0.363], {0.01:1.82}
	$40,001–60,000	71, (0.326), [0.244], {0.01:1.25}
	$60,001–90,000	54, (0.305), [0.222], {0.06:0.91}
	>$90,000	46, (0.298), [0.279], {0.00:1.17}
Income elasticity method	Cross sectional	246, (0.319), [0.293], {0.01:1.96}
	Inter-temporal	22, (0.554), [0.449], {0.00:1.82}
Income definition	Household income	175, (0.312), [0.302], {0.00:1.96}
	Personal income	93, (0.389), [0.334], {0.02:1.82}
Publication status	Journal	64, (0.479), [0.427], {0.02:1.96}
	Conference	81, (0.339), [0.307], {0.00:1.78}
	Published report	65, (0.289), [0.200], {0.01:1.25}
	Unpublished report	58, (0.239), [0.221], {0.01:1.17}
Study type	National study	155, (0.280), [0.252], {0.00:1.96}
	Non-national study	113, (0.418), [0.370], {0.01:1.25}
Country	United Kingdom	85, (0.259), [0.199], {0.00: 0.94}
	Netherlands	36, (0.303), [0.289], {0.01: 1.17}
	Norway	36, (0.306), [0.224], {0.07: 1.25}
	Sweden	24, (0.427), [0.470], {0.01: 1.82}
	Australia	19, (0.385), [0.371], {0.13: 1.78}
	United States	15, (0.235), [0.087], {0.16: 0.51}
	Other countries	53, (0.487), [0.407], {0.02: 1.96}
Data type	Stated preference	236, (0.324), [0.302], {0.00:1.96}
	Revealed preference	32, (0.443), [0.382], {0.02:1.58}
Choice context	Mode and route choice	2, (0.530), [0.509], {0.17:1.89}
	Mode choice	33, (0.425), [0.423], {0.02:1.78}
	Route choice	68, (0.258), [0.245], {0.00:1.94}
	Abstract choice	165, (0.352), [0.308], {0.01:1.96}
Experimental design	Orthogonal design	114, (0.297), [0.295], {0.00:1.96}
	Bradley design	64, (0.316), [0.278], {0.01:1.17}
	Efficient design	50, (0.421), [0.339], {0.02:1.82}
	Boundary ray	8, (0.070), [0.045], {0.01:0.14}
	Not relevant	32, (0.443), [0.382], {0.02:1.58}
Survey method	CAPI	69, (0.410), [0.359], {0.01:1.96}
	CATI	29, (0.387), [0.476], {0.01:1.82}
	Pen and paper	125, (0.289), [0.259], {0.00:1.58}
	Internet	45, (0.338), [0.224], {0.05:1.25}
Recruitment method	Internet panel	45, (0.337), [0.224], {0.05:1.25}
	Intercept	206, (0.326), [0.329], {0.00:1.96}
	Random digital dialling	17, (0.496), [0.320], {0.04:0.98}
Sample Size	≤500	49, (0.295), [0.308] {0.01:1.58}
	501–1000	60, (0.329), [0.325] {0.01:1.82}
	1001–2500	77, (0.345), [0.298] {0.00:1.96}
	2501–5000	55, (0.299), [0.273] {0.01:1.25}
	>5000	27, (0.505), [0.391] {0.08:1.78}
Model estimation space	Utility space	206, (0.321), [0.316], {0.00:1.96}
	Willingness to pay space	62, (0.395), [0.303], {0.02:1.82}
Functional form	Additive	199, (0.312), [0.308], {0.00:1.96}
	Multiplicative	69, (0.415), [0.322], {0.02:1.82}
Estimation model	Multinomial logit	184, (0.330), [0.302], {0.00:1.96}
	Mixed logit	52, (0.340), [0.362], {0.01:1.82}

(continued on next page)

Table 3 (*continued*)

Variable	Categories	Obs, (Mean), [Std Dev], {Min:Max}
	Nested logit	9, (0.393), [0.532], {0.04:1.78}
	Latent class	6, (0.361), [0.194], {0.17:0.68}
	Ordered logit	2, (0.534), [0.040], {0.50:0.56}
	Non-parametric	15, (0.370), [0.178], {0.07:0.66}
Taste Variation	Yes	73, (0.347), [0.319], {0.01:1.82}
	No	195, (0.335), [0.314], {0.00:1.96}

design offering time and cost trade-offs with an emphasis on gains and losses (Gunn, 2001) is the second most common with 27%. Efficient designs are more recent developments, and form around a fifth of cases, whilst the boundary ray approach advocated by Fowkes (1991) has rarely been used. Noticeably the most advanced experimental design method yields the largest elasticities on average.

By far the most common means of recruiting respondents was to intercept them during the course of their journey (76%), which has obvious attractions in terms of recruiting those making journeys of relevance whilst supporting cost effective on-mode surveys. Random digital dialling forms only 6% but its elasticities are on average larger.

The estimation method is dominated by the multinomial logit model which was the first to be used to deliver income elasticities of VTTS. This method represents just over two thirds of the sample. More recently, mixed logit and non-parametric methods have been applied, particularly in national studies, with the former being more popular and forming almost a fifth of the sample. There is not a great deal of variation in the income elasticities across estimation methods. Random taste variation has been allowed for in just over a quarter of cases with little impact on the mean income elasticity.

5. Meta-analysis

5.1. Preferred model

The meta-analysis takes the form of regression analysis, with the income elasticity being the variable to be explained and the set of independent variables taken from those set out in Table 3. The estimated model could take an additive or multiplicative form. The difference between the two is that in the latter the dependent variable is not simply the income elasticity but the natural logarithm of the income elasticity, whereupon the coefficients are interpreted as multiplicative impacts on the income elasticity rather than additive impacts. In the multiplicative form, zero income elasticities are excluded.

The R^2 goodness of fit of the two model forms cannot be directly compared given the dependent variable differs. Appropriate tests are the Mackinnon, White and Davidson (MWD) and Box-Cox tests (Baum and Baum, 2006; Shehata and Mickaiel, 2012). The results of the MWD test were inconclusive. However, the Box-Cox test produced statistically significant results indicating that the additive model performs better than the multiplicative model.[7] Comparing the results from both forms supports this finding, with the additive model returning larger t ratios for three quarters of the coefficient estimates and indeed on average 21% larger. The reported model therefore takes the form:

$$\mathscr{E}_{\mathrm{vtts,inc}_j} = \mu + \sum_{i=1}^{m} \gamma_i X_{ij} + \sum_{y=1}^{p} \sum_{s=1}^{q_p-1} \beta_{ys} Z_{jys} \ (j = 1, 2, \ldots N) \tag{2}$$

[7] To undertake the tests, the single zero elasticity was excluded in both forms of the meta-model tested.

where $\mathscr{E}_{\mathrm{vtts,inc}}$ represents the estimated income elasticity of VTTS in the k'th elasticity from the j'th study, and m is the number of continuous variables (X_{ij}) where γ_i denotes the effect of a unit change in X_i on the income elasticity. p is the number of categorial variables having q_p categories (Z_{jys}) and β_{ys} indicates the additive effect of a specific indicator category relative to its arbitrarily omitted base. All models were estimated using STATA software (StataCorp, 2015). Prior to reporting the preferred meta-model, we discuss a number of issues dealing with the quality of the assembled data and the treatment of those quality related issues. Not all evidence will be of the same quality, and a criticism sometimes levelled at meta-analysis is that data is pooled across studies with insufficient consideration of variations in quality.

As a means of removing the 5% of elasticities that might be deemed of the poorest quality or most difficult to explain, 'outliers' with standardised residuals outside the range ±1.96 have been excluded and the models re-estimated. The preferred model reported in Table 4 contains 14 terms in addition to the constant. Of these, 12 are significant at the 5% level but 6 were not prior to removal of the outliers, whilst the remaining 2 coefficients have t ratios of 1.4 and 1.8 but these had been 0.2 and 0.4 respectively. All but one of the coefficient estimates became more significant after the removal of the outliers and indeed the average t ratio increases by 67% from 1.80 to 3.00. The adjusted R^2 increased markedly from 0.196 to 0.290. This process has been valuable in delivering a more robust meta-model.

The precision with which income elasticities are estimated can also be taken to represent to some degree their quality. In the absence of a comprehensive set of confidence intervals for the elasticity estimates, the sample size used in estimation is taken as a proxy. Using a variety of functional forms in weighted least squares, it was found that the estimated parameters and their standard errors hardly varied. Nor did categories of sample size impact on the income elasticities when entered as explanatory variables. In addition, the status of the publication can also be taken as a proxy for various aspects of a study's quality. We distinguished studies that were published in academic journals, presented at conferences, published in non-refereed media or unpublished. We would expect journal articles to be of the highest quality and it turned out that an effect was apparent to which we return below.

We have also explored quality issues in terms of the error structure of the model. Random-effects (RE) and Fixed-effects (FE) models were specified that take into account the panel nature of the dataset (repeated observations for the same country). These estimation approaches can improve the efficiency (precision) of estimation (RE) or reduce bias in estimation (FE). This is because in random effects correlations between errors from observations of the same country are explicitly accounted for in estimation. For fixed effects correlations between errors and

Table 4
Estimation results for the Random Effects Meta Model.

Category	Variable	Coefficient (t ratio)
Constant		1.091 (4.9)
Economic variable	Natural logarithm income	−0.064 (3.1)
Income definition	Personal income	0.052 (1.8)
Elasticity method	Inter-temporal	0.173 (3.4)
Survey year	After 2005	−0.076 (2.3)
Transport mode	Non-car	−0.083 (3.0)
Journey purpose	Non-commuting	0.079 (3.0)
Data type	RP	−0.075 (1.4)
Publication status	Conference	−0.133 (3.1)
	Published report	−0.160 (4.1)
	Unpublished report	−0.176 (4.3)
Recruitment method	Internet panel	0.115 (3.0)
Study	A	−0.205 (2.0)
	B	−0.163 (2.3)
	C	0.475 (5.1)
Variance country		0.19
Adjusted R^2		0.290
Observations		257

regressors are explicitly accounted for in estimation. We have chosen to develop the panel by considering country as the cross sectional identifier for two reasons. Firstly we expect there to be some unobserved heterogeneity between countries reflecting such things as cultural preferences for travel and/or environmental factors. Secondly, we rarely have more than one elasticity value per study and so cannot use the study as the cross sectional identifier as there would be an abundance of single cross sections. As such, even with a country cross sectional specification, the panel is unbalanced.

The two models produce the same signs of all the coefficients with a slightly higher magnitude of all the coefficients in the RE model when compared to the OLS model. The Hausman test is used to compare the two estimators derived from the FE and RE models, and indicated a better performance of the RE model (Hausman, 1978). The results of the test gave a p-value of 0.3263 ($\chi^2 = 14.70$) and the null hypothesis cannot be rejected. Therefore, the preferred model is the RE model. It accounts for the nature of the dataset that contains multiple elasticities from the same country.

Some meta-analyses have specified study specific 'fixed effects' as a means of discerning differences in quality across the studies covered that have a systematic effect and retaining those significant at some pre-specified level (Wardman, 2012, 2014; Wardman et al., 2016). We have been reluctant to pursue study specific effects based on the full set possible since they may to varying degrees discern effects attributable to the main variables. Indeed, when we specified dummy variables for all studies with more than one elasticity observation, we found that although only nine were significant even at the 10% level there were then only four main effects significant at that level and only two at the usual 5% level, despite the adjusted R^2 measure increasing appreciably to 0.411. We therefore adopted a more selective approach, recognising that there could indeed be some studies that are of poor quality or which provided income elasticities that are difficult to explain. The standardised residuals of studies with four or more observations were inspected to identify common trends. There were five studies that had standardised residuals that were all or nearly all of the same sign. Three of these yielded significant study specific effects and were retained.

Finally, multicollinearity tests indicated this was not a problem. The variance inflation factor (VIF) is less than 3 for all the independent variables in the reported model and the correlations between all the estimated coefficients are less than 0.40 (Wooldridge, 2010).

6. Meta-model results

The preferred additive meta-model is reported in Table 4 and takes the form of a RE model where the effect is country and it omits observations with standardised residuals outside the range ±1.96. The adjusted R^2 goodness of fit measure of 0.290 is low compared to figures typically exceeding 0.5 in meta-analyses of VTTS.[8] It is to be expected that it is harder to explain variations in the VTTS income elasticity across studies than variations in VTTS across studies. The VTTS is influenced strongly by a wide range of factors, including mode, journey purpose, income, distance, data type and indeed interactions amongst them, but these impacts can be expected to cancel out to varying extents when looking at second order effects such as changes in VTTS with income which will therefore be inherently more difficult to explain.

Income is a continuous variable, expressed in dollars per annum, and enters in logarithmic form since this provided a better fit to the data. The income elasticity falls as income rises but at a diminishing rate. The implied variation in the income elasticity as income increases is relatively minor though. For example, if annual income increases approximately from \$20,000 to \$100,000, representing the difference between the 10th and 90th percentiles of income in the data set, then the income elasticity falls by only 11%. However, Börjesson et al. (2012) used an exact repeat stated preference method and found contrasting results. It was based on data collected in 1994 and 2007, with the same questionnaire design and method except for the cost level, which increased by 40% to account for inflation. They found that the income elasticity of the VTTS increases when the income increases and non-constant cross-sectional elasticity by income level can be used as an inter-temporal elasticity. From a theoretical point of view, variation of the VTTS might differ between the cross-sectional and inter-temporal elasticities which vary with respect to income changes, time allocation to consumption changes and time requirement changes to activities (Jiang and Morikawa, 2004), as discussed in section 2.

The income used in estimating the income elasticity could be household or personal. Although not quite significant at the 5% level, the income elasticity is 0.05 larger when personal income was used. This might be attributed to a greater degree of control over what personal income is spent on, although greater uncertainty surrounding households than personal income might have contributed. Fowkes (1986) found an impressive relationship between the VTTS and personal income, supporting a cross-sectional income elasticity of around unity, much larger than the income elasticities typically estimated for household income. Fowkes (1986), for example, used personal income to estimate the VTTS; thus, the income elasticity can depend on how respondents perceive their incomes allocated to travel. Whilst the effect here is positive, it would by no means imply a cross-sectional income elasticity of one.

The income elasticities can be cross-sectional, obtained from variations in VTTS across income groups at a single point in time, or inter-temporal, reflecting variations over time. One of the strongest impacts apparent in the meta-model is that inter-temporal elasticities are larger than their cross-sectional equivalents to the extent of 0.173. We do not regard this finding that the cross-sectional income elasticity of the VTTS is smaller than the intertemporal one as counter-intuitive. First, by their very nature, variation over time and variation between persons are different animals, which can differ from each other, and the difference could go both ways. A connection between the two is that changes in the VTTS over time can be the result of changes in the composition of the population. Secondly, both cross-sectional analysis and time series analysis of the income elasticity of the VTTS can suffer from the problem that other, but possibly correlated, factors (between persons or between years) than income also affect the VTTS, such as employment status of a person and increasing opportunities to make worthwhile use of travel time (e.g. to work in the train). We would not want to claim that time series models are better in controlling for these other factors than cross-sectional models (given the richness of influencing factors in many of the cross-sectional models in this field, this could very well be the other way around).

Related to this latter issue is whether the income elasticity varies over time. Different categories of year were tested for every 10 and 5 years and only 2005 had a significant effect when included in the meta-model. It was found that the income elasticity is less in studies conducted after 2005. This might reflect the aforementioned effect that there is less of an incentive to spend increased income on time savings if those time savings have lesser benefit. The marginal disutility of travel time has fallen because the digital revolution has meant that better use can be made of travel time.

The income elasticity varied little by mode with the exception that those relating to modes other than car tended to be lower. A combined term for non-car indicated that the income elasticity is 0.083 lower than for car. Given that car users self-select on the basis of high values of time, they might be expected to have larger income elasticities since time savings are more important to them. In addition, the impacts of the digital revolution on the marginal utility of travel time will have been proportionately more for the non-car modes. This is in line with Börjesson and Eliasson (2018) who reported a 0.5 income elasticity for cars and 0.17 for public transport, though within the study variations in

[8] Some of those studies estimated multiplicative models and for reference the comparable model here achieved an adjusted R^2 of 0.244.

income elasticity by modes are common. Furthermore, effective use of travel time could be easier in non-car modes, such as working on the train, and therefore the effect of increases in income on the VTTS might be dampened.

The only journey purpose effect was a difference between commuters and non-commuters, with the latter having income elasticities 0.079 larger. This might reflect an income effect, in that purchasing time savings for regularly made commuting trips incurs greater overall expense. Business and other travel purposes have higher income elasticities reported in (Hague Consulting Group, 1998; Accent and Group, 1999; Fosgerau, 2005; Tapley et al., 2007; Axhausen et al., 2008; De Jong et al., 2014; Batley et al., 2017).

The difference between SP and RP for VTTS has been investigated in several studies, including the meta-analysis of Wardman et al. (2016). The main finding was not consistent with previous results by Shires and De Jong (2009), as the coefficient reflecting RP data indicates lower values compared with SP data values. Meta-analysis tends to find data type to impact on estimated VTTS and demand elasticities. We therefore retained the RP effect even though it is not quite significant at the 10% level. Another justification for its retention is that it might be argued that RP models are useful in providing a benchmark for first order effects, and hopefully actual choice based support for the evidence obtained from the widely used but hypothetical SP method, but they are not well suited to the estimation of second order effects and thus any divergences should be isolated. The results indicate that the income elasticity is lower, although only slightly so, when based on actual behaviour.

It can be seen that conference papers, published reports and unpublished reports all yield income elasticities lower than for journal articles. It might be argued that second order effects are more difficult to estimate and hence the presumably higher quality research disseminated in journal articles leads to higher estimates. The effects apparent here are amongst the largest in the meta-model.

The recruitment method could be intercept while travelling, random digit dialling or making use of an internet panel. There is some scepticism about the reliability of data obtained from internet panels, on the grounds that respondents are paid to answer surveys and those with lower incomes tend to be over-represented. It is therefore important to isolate any possible effect and it emerged that internet panel surveys deliver income elasticities that are 0.115 larger.

As already discussed, we took a selective approach to the specification of study specific effects and three studies were identified that had residuals that consistently indicated that the predicted income elasticity was too large or too small. Whilst there was no apparent reason for these effects, such as an omitted variable or atypical set of circumstances, it turns out that the net effect essentially cancels out, given Studies A and C have 6 observations and Study B has 9. The decision as to whether these effects should be included or not in estimating implied income elasticities is immaterial since from amongst the 267 observations the net effect of these 21 observations on the constant term would be negligible.

6.1. Implied income elasticities of the VTTS

Table 5 presents income elasticities implied by the estimated meta-model for a range of scenarios characterised by income level, mode, journey purpose, whether the income elasticity is cross-sectional or inter-temporal, and whether personal or household income underpins the income elasticity. As far as other variables are concerned, the data type is taken to be SP, on the grounds that we contend it is the most suitable for estimating second order effects such as income elasticities,[9] the publication status is journal paper on the grounds that these are expected to be highest quality, and the survey year is after 2005.

The range of implied elasticities is based on the data upon which the meta-model was estimated. So where personal income elasticities are reported, they are based on minimum, first quartile, mean, third quartile and maximum incomes of $3084, $29,187, $51,442, $63,693 and $180,393. The corresponding distribution of household income turn out to be not greatly different and are respectively $3616, $33,562, $48,244, $86,830 and $268,021.

Some large variations in the implied income elasticity by income level can be observed, but this is a function of the very large differences between the minimum and maximum income levels. Restricting consideration to the elasticities that lie in the inter-quartile range of incomes, the variations in the income elasticities are relatively minor, particularly compared with the variations by mode and journey purpose.

The income elasticities are somewhat larger when derived from personal income but it is the variation between cross-sectional and inter-temporal income elasticities that is of greatest interest as discussed in Section 2. The implied cross-sectional elasticities very much support the view that they are less than one with a value around 0.5 being a typical figure. Given that official appraisal practice increases recommended VTTS in line with income, there is a stark contrast between this practice and the most common means of estimating VTTS and its income elasticity. However, when we turn to the inter-temporal elasticities, and restricting consideration to the inter-quartile range of incomes, there would be greater support for an income elasticity of unity depending on the choices made in the simulation (e.g. SP, published …), particularly bearing in mind that there might have been trend reductions in VTTS over time independent of income due to the digital revolution and the impact of being able to undertake more and better activities while travelling which will reduce the VTTS. With regard to the latter point, it is noticeable that the car income elasticities are between 0.5 and 0.9, and it is here where we would expect the digital revolution to have had the least impact on the marginal utility of travel time.

The support for an income elasticity of one is strengthened if we take the view that personal income provides a more appropriate basis for valuation on the grounds that travellers will be more familiar with it and it drives personal behaviour more than household income. Our preference would be to base inter-temporal income elasticity recommendations on inter-temporal evidence. In summary, therefore, and bearing in mind that other inter-temporal effects apparent over the period will have operated to reduce the inter-temporal elasticity but that they are likely to be transitory, we feel that our findings provide support for the widely used convention in official appraisal practice of increasing VTTS over time in line with income.

7. Conclusion

The present study provides the first meta-analysis specifically focussed on within-study variations in VTTS according to income. It is significant in that it provides a measure of support for the widespread convention in official appraisal guidance of increasing VTTS in line with income in the face of the somewhat lower income elasticities common in national VTTS studies that are conducted to inform official guidance.

The study explained the variation in income elasticity of the value of travel time savings (VTTS) that is estimated in the literature with respect

[9] Whilst robust RP models are attractive to many commentators in terms of providing VTTS estimates, the generally limited sample sizes and/or reliance on network data mean that they are not as well placed to provide reliable estimates of variations in VTTS. Although the absolute VTTS from SP studies might be questioned, since they are not based on actual behaviour, it is generally felt that the variations in VTTS from SP evidence are robust.

Table 5
Implied income elasticities of the VTTS.

	Inter-temporal income elasticity using personal income				Inter-temporal income elasticity using household income				Cross-sectional income elasticity using personal income				Cross-sectional income elasticity using household income			
	C/C	PT/C	C/O	PT/O	C/C	PT/C	C/O	PT/O	C/C	PT/C	C/O	PT/O	C/C	PT/C	C/O	PT/O
Min	**0.89**	**0.73**	**1.03**	**0.87**	**0.78**	**0.62**	**0.92**	**0.76**	**0.54**	**0.38**	**0.70**	**0.54**	**0.43**	**0.27**	**0.59**	**0.43**
25%	**0.75**	**0.59**	**0.89**	**0.73**	**0.64**	**0.48**	**0.78**	**0.62**	**0.40**	**0.24**	**0.56**	**0.40**	**0.29**	**0.13**	**0.45**	**0.29**
Mean	**0.72**	**0.56**	**0.86**	**0.70**	**0.62**	**0.46**	**0.76**	**0.60**	**0.37**	**0.21**	**0.53**	**0.37**	**0.27**	**0.11**	**0.43**	**0.27**
75%	**0.71**	**0.55**	**0.85**	**0.69**	**0.59**	**0.43**	**0.73**	**0.57**	**0.36**	**0.20**	**0.52**	**0.36**	**0.24**	**0.08**	**0.40**	**0.24**
Max	**0.64**	**0.48**	**0.78**	**0.62**	**0.52**	**0.36**	**0.66**	**0.50**	**0.29**	**0.13**	**0.45**	**0.29**	**0.17**	**0.01**	**0.33**	**0.17**

Note: C/C, PT/C, C/O and PT/O denote car mode for commute, public transport for commute, car mode for other journey purposes (business and leisure), public transport for other journey purposes categories respectively.

to differences in study characteristics and methodologies. A meta-analysis method has been undertaken to achieve this explanation. The paper presents estimation results for the random-effects model (RE), which accounted for the multiple income elasticities for the same country.

The meta-model observed a variety of factors that affect the income elasticity of the VTTS, which leads to understanding the variation. An increase income level influenced how individuals value travel time, and thus their income elasticity changed. This change in income level will affect the income elasticity by first increasing and then becoming less reactive to changes in income level. This income elasticity can be used in planning to build new or improve transport infrastructure, and it is considered a key factor that influences VTTS (Fosgerau, 2005).

Additionally, this study offers several empirical findings to explain the variation in income elasticity of the VTTS. First, it highlights the difference in the income elasticity for each income definition used in the study, as demonstrated by the remarkable variation between the estimated income elasticity when using personal or household. Second, it shows that income elasticity differs significantly depending on the elasticity method, where inter-temporal elasticity was found to have a significantly higher income elasticity than cross-sectional elasticity, which supports the finding reported in studies that income elasticity estimated in cross-sectional studies is lower (Rich and Vandet, 2019). Third, income elasticity differs for different transport modes and journey purposes, as people who use each type of mode and journey have different income levels and therefore differences in income elasticity (Axhausen et al., 2008; Batley et al., 2017; Börjesson and Eliasson, 2018).

Fourth, different methodological variables were included in the meta-model to explain income elasticity of the VTTS variations. Although our findings show variations in income elasticity when using different recruitment methods, it is difficult to draw any conclusions on which method is the more appropriate to adopt to estimate income elasticity. Finally, several of the estimated coefficients in our initial meta-model are not significantly different from zero such as distance and methodological factors; these coefficients need further examination by researchers and decision-makers interested in the estimated income elasticity of the VTTS.

The results of this study indicate that the income elasticity of the VTTS has a large variation and that further explanatory variables still need to be found. The income elasticities are likely to depend on study-specific characteristics such as the type of elasticity, the income definition used, transport mode and journey purpose. However, national VTTS studies routinely find variations in VTTS itself by key factors such as mode, purpose and distance but it is up to policy makers to decide whether these distinctions should be adopted in appraisal guidance and it is not uncommon that they are not. For appraisal, using the inter-temporal income elasticity would seem to be more appropriate than using cross-sectional elasticity since it explicitly examines changes over time which is what cost-benefit analysis requires.

Regarding the meta-model, we used different models to obtain more precise results by considering the multiple estimates derived from various countries. This methodology can be enhanced in future research by using more advanced meta-models from other fields, such as medicine. For instance, all studies included in the meta-model can be weighted by their quality by applying a quality assessment tool for scoring each study's quality based on several quality criteria. This quality assessment tool can assess the validity of the survey recruitment method, the type of data and the estimation model used in a given study. Then, the quality score can be used in regression as an analytical weight (Higgins and Green, 2008, 2011). In addition, using the standard error and its inverse-variance of the income elasticity is more appropriate to account for precision in the weighted model instead of square root of sample size used in the study (Borenstein, 2009). These standard errors are often not reported in the underlying studies and make a plea for reporting these in future studies.

Author statement

We the undersigned declare that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere. We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us. We understand that the Corresponding Author is the sole contact for the Editorial process. He/she is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs.

Declaration of competing interest

No potential conflict of interest was reported by the authors.

Data availability

Data will be made available on request.

Acknowledgement

The first author gratefully acknowledges the Princess Nourah bint Abdulrahman University for funding her PhD programme at the University of Leeds.

Appendix 1

Studies included in the meta-analysis dataset.

Study no	Study name	Country
1	Axhausen et al. (2008)	SWITZERLAND
2	Román et al. (2014)	SPAIN
3	Beca Carter Hollings and Ferner With Steer Davies Gleave (2022)	NEW ZEALAND
4	Ramjerdi et al. (2010)	NORWAY
5	Fosgerau et al. (2007)	DENMARK
6	Algers et al. (1995)	SWEDEN
7	Börjesson et al. (2012)	SWEDEN
8	Ramjerdi et al. (1997)	NORWAY
9	Small (2012)	USA
10	Fosgerau (2005)	DENMARK
11	Hague Consulting Group (1990)	NETHERLANDS
12	Hague Consulting Group (1998)	NETHERLANDS
13	Significance and Bates Services (2012)	NETHERLANDS
14	Batley et al. (2017)	UNITED KINGDOM
15	Mackie et al. (2003)	UNITED KINGDOM
16	Accent and Group (1999)	UNITED KINGDOM
17	Athira et al. (2016)	INDIA
18	Ahsan et al. (2002)	BANGLADESH
19	Legaspi and Douglas (2015)	AUSTRALIA
20	Beck et al. (2017)	SWEDAN
21	Authority (2009)	SINGAPORE
22	Smith (1999)	AUSTRALIA
23	Radovich and Foster (2000)	NEW ZEALAND
24	MVA (1987)	UNITED KINGDOM
25	Sanko et al. (2014)	UNITED KINGDOM
26	Hess et al. (2011)	USA
27	Douglas (2017)	AUSTRALIA
28	Lu et al. (2018)	DENMARK
29	Merkert and Beck (2017)	AUSTRALIA
30	Bradley et al. (1986)	UNITED KINGDOM
31	Fowkes (1986)	UNITED KINGDOM
32	Kolarova et al. (2018)	GERMAN
33	Börjesson and Eliasson (2018)	SWEDEN
34	Amador et al. (2008)	CHILE
35	Obermeyer et al. (2014)	SWITZERLAND
36	de Dios Ortúzar and Simonetti (2008)	CHILE
37	Wardman (2006)	UNITED KINGDOM
38	Pursula and Kurri (1996)	FINLAND
39	Wardman (2001a)	UNITED KINGDOM
40	Tapley et al. (2007)	UNITED KINGDOM
41	Wardman et al. (2018)	UNITED KINGDOM
42	Jara-Díaz and Guevara (2003)	CHILE
43	Thomas and Thompson (1970)	USA
44	Davies and Rogers (1973)	UNITED KINGDOM
45	Wardman et al. (2008)	UNITED KINGDOM
46	Gunn (2001)	NETHERLANDS
47	Wardman (2001b)	UNITED KINGDOM
48	Swärdh (2008)	Sweden
49	Flugel et al. (2020)	NORWAY

References

Abrantes, P.A., Wardman, M.R., 2011. Meta-analysis of UK values of travel time: an update. Transport. Res. Pol. Pract. 45, 1–17.

Accent, Research, Group, H.C., 1999. The Value of Time on Uk Roads. Ahcg The Hague, Netherlands.

Ahsan, H.M., Rahman, M.M., Habib, K.M.N., 2002. INTER-CITY BUS PASSENGERS: BANGLADESH PERSPECTIVE.

Algers, S., Dillen, J.L., Widlert, S., 1995. The National Swedish Value of Time Study. PTRC European Transportation Forum, Warwick.

Amador, F.J., González, R.M., De Dios Ortúzar, J., 2008. On confounding preference heterogeneity and income effect in discrete choice models. Network. Spatial Econ. 8, 97–108.

Athira, I., Muneera, C., Krishnamurthy, K., Anjaneyulu, M., 2016. Estimation of value of travel time for work trips. Transport. Res. Procedia 17, 116–123.

Authority, S.L.T., 2009. In: LTD, M.A.P. (Ed.), Update of Economic Evaluation Parameters. Final Report (Singapore).

Axhausen, K.W., Hess, S., König, A., Abay, G., Bates, J.J., Bierlaire, M., 2008. Income and distance elasticities of values of travel time savings: new Swiss results. Transport Pol. 15, 173–185.

Batley, R., Bates, J., Bliemer, M., Börjesson, M., Bourdon, J., Cabral, M.O., Chintakayala, P.K., Choudhury, C., Daly, A., Dekker, T., 2015. Values of Travel Time Savings and Reliability: Final Reports. Department for Transport. https://www.gov.uk/government/publications/values-of-travel-time-savings-and-reliability-final-reports.

Batley, R., Bates, J., Bliemer, M., Börjesson, M., Bourdon, J., Cabral, M.O., Chintakayala, P.K., Choudhury, C., Daly, A., Dekker, T., 2017. New Appraisal Values of Travel Time Saving and Reliability in Great Britain. Transportation, pp. 1–39.

Baum, C.F., Baum, C.F., 2006. An Introduction to Modern Econometrics Using Stata. Stata press.

Beca Carter Hollings, Ferner With Steer Davies Gleave, F., 2022. Review of Benefit Parameter Values for Economic Evaluation: Final Report. Transfund New Zealand.

Beck, M.J., Hess, S., Cabral, M.O., Dubernet, I., 2017. Valuing travel time savings: a case of short-term or long term choices? Transport. Res. E Logist. Transport. Rev. 100, 133–143.

Becker, G.S., 1965. A theory of the allocation of time. Econ. J. 493–517.

Beesley, M.E., 1965. The value of time spent in travelling: some new evidence. Economica 32, 174–185.

Borenstein, M., 2009. Introduction to Meta-Analysis. John Wiley & Sons, Chichester.

Börjesson, M., Eliasson, J., 2014. Experiences from the Swedish value of time study. Transport. Res. Pol. Pract. 59, 144–158.

Börjesson, M., Eliasson, J., 2018. Should values of time be differentiated? Transport Rev. 1–19.

Börjesson, M., Fosgerau, M., Algers, S., 2012. On the income elasticity of the value of travel time. Transport. Res. Pol. Pract. 46, 368–377.

Bradley, M., Marks, P., Wardman, M., 1986. SUMMARY OF FOUR STUDIES INTO THE VALUE OF TRAVEL TIME SAVINGS.

Button, K., 1995. What can meta-analysis tell us about the implications of transport? Reg. Stud. 29, 507–517.

Button, K., 2019. The value and challenges of using meta-analysis in transportation economics. Transport Rev. 39, 293–308.

Chalmers, I., Altman, D.G., 1997. Systemic Reviews. Bmj publishing Group.

Cleophas, T.J., Zwinderman, A.H., 2007. Meta-analysis. Circulation 115, 2870–2875.

Davies, A., Rogers, K., 1973. Modal Choice and the Value of Time. Local Government Operational Research Unit, Royal Institute of Public.

De Dios Ortúzar, J., Simonetti, C., 2008. Modelling the demand for medium distance air travel with the mixed data estimation method. J. Air Transport. Manag. 14, 297–303.

De Jong, G., Kouwenhoven, M., Bates, J., Koster, P., Verhoef, E., Tavasszy, L., Warffemius, P., 2014. New Sp-values of time and reliability for freight transport in The Netherlands. Transport. Res. E Logist. Transport. Rev. 64, 71–87.

Department For Transport, 2018. Cost-benefit analysis. *TAG Unit A1. 1*. https://www.gov.uk/government/publications/webtag-tag-unit-a1-1-cost-benefit-analysis-may-2018.

Deserpa, A.C., 1971. A theory of the economics of time. Econ. J. 81, 828–846.

Douglas, N., 2017. Valuing Ferry Service Quality Using a Combined Rating & Stated Preference Survey, 39th. Australasian Transport Research Forum (Atrf), Auckland, New Zealand, 2017.

Elvik, R., 2005. Introductory guide to systematic reviews and meta-analysis. Transport. Res. Rec.: J. Transport. Res. Board 230–235.

Flugel, S., Halse, A.H., Hulleberg, N., Jordbakke, G.N., Veisten, K., Sundfør, H.B., Kouwenhoven, M., 2020. Value of Travel Time and Related Factors: Technical Report, the Norwegian Valuation Study 2018-2020.

Fosgerau, M., 2005. Unit Income Elasticity of the Value of Travel Time Savings. 8th nectar conference, las palmas gc june, pp. 2–4.

Fosgerau, M., Hjorth, K., Lyk-Jensen, S.V., 2007. The Danish value of time study. In: Danmarks Transport Forskning Report.

Fowkes, A., 1991. Recent developments in stated preference techniques in transport research. In: PLANNING AND TRANSPORT RESEARCH AND COMPUTATION, 347.

Fowkes, T., 1986. The UK department of transport value of time project. Int. J. Transport Econ. /Rivista internazionale di economia dei trasporti 197–207.

Glass, G.V., 1976. Primary, secondary, and meta-analysis of research. Educ. Res. 5, 3–8.

Gunn, H., 2001. Spatial and temporal transferability of relationships between travel demand, trip cost and travel time. Transport. Res. E Logist. Transport. Rev. 37, 163–189.

Gunn, H.F., Sillaparcharn, P., 2007. An Introduction to the Valuation of Travel Time-Savings and Losses. Handbook of Transport Modelling, second ed. Emerald Group Publishing Limited.

Hague Consulting Group, R.T.C.A.N., 1990. The Netherlands''value of Time'study: Final Report. Report to Dienst Verkeerskunde, Rijkswaterstaat, The Hague.

Hague Consulting Group, R.T.C.A.N., 1998. Value of Dutch Travel Time Savings in 1997 – Final Report. Prepared for Rijkswaterstaat – Avv, Netherlands.

Hausman, J.A., 1978. Specification tests in econometrics. Econometrica: J. Econom. Soc. 1251–1271.

Hensher, D., 2019. Using the Average Wage Rate to Assess the Merit of Value of Travel Time Savings: A Concern and Clarification. Findings, p. 5772.

Hensher, D.A., 2001. Measurement of the valuation of travel time savings. J. Transport Econ. Pol. 35, 71–98.

Hess, S., Greene, E.R., Falzarano, C.S., Muriello, M., 2011. Pay to drive in my bus lane: a stated choice analysis for the proposed Lincoln Tunnel Hot lane into Manhattan. Transport Pol. 18, 649–656.

Higgins, J.P., Green, S., 2008. Cochrane Handbook for Systematic Reviews of Interventions.

Higgins, J.P., Green, S., 2011. Cochrane Handbook for Systematic Reviews of Interventions. John Wiley & Sons.

Ioannidis, J.P., Lau, J., 1999. Pooling research results: benefits and limitations of meta-analysis. Joint Comm. J. Qual. Patient Saf. 25, 462–469.

Jara-Díaz, S.R., 2000. Allocation and valuation of travel time savings. Handb. Transp. 1, 303–319.

Jara-Díaz, S.R., Guevara, C.A., 2003. Behind the subjective value of travel time savings. J. Transport Econ. Pol. 37, 29–46.

Jiang, M., Morikawa, T., 2004. Theoretical analysis on the variation of value of travel time savings. Transport. Res. Pol. Pract. 38, 551–571.

Johnson, M.B., 1966. Travel time and the price of leisure. Econ. Inq. 4, 135–145.

Kolarova, V., Steck, F., Cyganski, R., Trommer, S., 2018. Estimation of the value of time for automated driving using revealed and stated preference methods. Transport. Res. Procedia 31, 35–46.

Laird, J., Bates, J., Mackie, P., 2013. In: Transport, Df (Ed.), Peer Review of Proposals for Updated Values of Travel Time Savings.

Legaspi, J., Douglas, N., 2015. Value of travel time revisited–NSW experiment. In: Proc. 37th Australasian Transport Research Forum.

Litman, T., 2021. Not So Fast-Better Speed Valuation for Transportation Planning.

Lu, H., Rohr, C., Patruni, B., Hess, S., Paag, H., 2018. In: Quantifying Travellers' Willingness to Pay for the Harbour Tunnel (Copenhagen).

Mackie, P., Jara-Diaz, S., Fowkes, A., 2001. The value of travel time savings in evaluation. Transport. Res. E Logist. Transport. Rev. 37, 91–106.

Mackie, P., Wardman, M., Fowkes, A., Whelan, G., Nellthorp, J., Bates, J., 2003. Values of Travel Time Savings (UK).

Martens, K., Di Ciommo, F., 2017. Travel time savings, accessibility gains and equity effects in cost–benefit analysis. Transport Rev. 37, 152–169.

Mcdonald, J.F., 1975. Variations in the value of reductions in commuting time. J. Urban Econ. 2, 265–277.

Merkert, R., Beck, M., 2017. Value of travel time savings and willingness to pay for regional aviation. Transport. Res. Pol. Pract. 96, 29–42.

Metz, D., 2008. The myth of travel time saving. Transport Rev. 28, 321–336.

Metz, D., 2021. Economic benefits of road widening: discrepancy between outturn and forecast. Transport. Res. Pol. Pract. 147, 312–319.

Mva, I.A.T., 1987. Value of Travel Time Savings. Policy Journals, Newbury, Berkshire, England.

Obermeyer, A., Treiber, M., Evangelinos, C., 2014. Thresholds in Choice Behaviour and the Size of Travel Time Savings. *arxiv preprint arxiv:1402.3433*.

Ojeda-Cabral, M., Batley, R., Hess, S., 2016. The value of travel time: random utility versus random valuation. Transportmetrica: Transport. Sci. 12, 230–248.

Oort, C.J., 1969. The evaluation of travelling time. J. Transport Econ. Pol. 279–286.

Pursula, M., Kurri, J., 1996. Value of Time Research in Finland. Proceedings of the Value of Time Seminar, Held 29-30 October 1996. Session, vol. 4.

Quarmby, D.A., 1967. Choice of travel mode for the journey to work: some findings. J. Transport Econ. Pol. 273–314.

Radovich, B., Foster, J., 2000. Urban travel time value-some New Zealand findings. Road Transp. Res. 9, 27.

Ramjerdi, F., Flugel, S., Samstad, H., Killi, M., 2010. Value of Time, Safety and Environment in Passenger Transport–Time. TØI report B, p. 1053.

Ramjerdi, F., Rand, L., Sætermo, I.-A.F., Sælensminde, K., 1997. The Norwegian Value of Time Study Part I. Institute of Transport Economics, Oslo.

Rich, J., Vandet, C.A., 2019. Is the value of travel time savings increasing? Analysis throughout a financial crisis. Transport. Res. Pol. Pract. 124, 145–168.

Román, C., Martín, J.C., Espino, R., Cherchi, E., De Dios Ortuzar, J., Rizzi, L.I., González, R.M., Amador, F.J., 2014. Valuation of travel time savings for intercity travel: the Madrid-Barcelona corridor. Transport Pol. 36, 105–117.

Sanko, N., Hess, S., Dumont, J., Daly, A., 2014. Contrasting imputation with a latent variable approach to dealing with missing income in choice models. J. Choice Model. 12, 47–57.

Shehata, E., Mickaiel, S., 2012. Lmfreg: Stata Module to Compute Ols Linear vs Log-Linear Functional Form Tests.

Shires, J.D., De Jong, G.C., 2009. An international meta-analysis of values of travel time savings. Eval. Progr. Plann. 32, 315–325.

Significance, V.U.A., Bates Services, John, 2012. Values of Time and Reliability in Passenger and Freight Transport in The Netherlands. Ministry of Infrastructure and the Environment, Netherlands.

Small, K.A., 2012. Valuation of travel time. Econ. Transport. 1, 2–14.

Smith, B., 1999. The good/leisure tradeoff and the value of travel time savings. Road Transp. Res. 8, 74.

Statacorp, L., 2015. Stata Statistical Software: Release 14. StataCorp LP, College Station, TX [computer program].

Swärdh, J.-E., 2008. Is the intertemporal income elasticity of the value of travel time unity? Statens väg-och transportforskningsinstitut.

Tapley, N., Wardman, M., Gunn, H., Hyman, G., 2007. Inter-temporal variations in values of time in Great Britain. In: PROCEEDINGS OF THE EUROPEAN TRANSPORT CONFERENCE 2007 HELD 17-19 OCTOBER 2007. LEIDEN, THE NETHERLANDS.

Thomas, T.C., Thompson, G.I., 1970. The Value of Time for Commuting Motorists as a Function of Their Income Level and Amount of Time Saved. Highway Research Record.

Train, K., Weeks, M., 2005. Discrete Choice Models in Preference Space and Willingness-To-Pay Space. Applications of Simulation Methods in Environmental and Resource Economics. Springer.

Tranter, P.J., 2010. Speed kills: the complex links between transport, lack of time and urban health. J. Urban Health 87, 155–166.

Van Geenhuizen, M., Rietveld, P., Reggiani, A., 2016. Equity Issues in the Evaluation of Transport Policies and Transport Infrastructure Projects. *Policy Analysis Of Transport Networks*. Routledge.

Van Goeverden, C.D., 2022. The value of travel speed. Transp. Res. Interdiscip. Perspect. 13, 100530.

Wampold, B.E., Ahn, H., Kim, D., 2000. Meta-analysis in the social sciences. Asia Pac. Educ. Rev. 1, 67–74.

Wang, Y., Levinson, D., 2022. Time savings vs. Access-based benefit assessment of New York's second avenue subway. J. Benefit-Cost Anal. 13, 120–147.

Wardman, M., 1998. The value of travel time: a review of British evidence. J. Transport Econ. Pol. 285–316.

Wardman, M., 2001a. Inter-temporal Variations in the Value of Time. Its Working Paper 566. ITS Leeds, UK.

Wardman, M., 2001b. A review of British evidence on time and service quality valuations. Transport. Res. E Logist. Transport. Rev. 37, 107–128.

Wardman, M., 2006. M4 Toll Passenger Stated Preference Modellin (United Kingdom).

Wardman, M., 2012. Review and meta-analysis of UK time elasticities of travel demand. Transportation 39, 465–490.

Wardman, M., 2014. Price elasticities of surface travel demand a meta-analysis of UK evidence. J. Transport Econ. Pol. 48, 367–384.

Wardman, M., Chintakayala, V.P.K., De Jong, G., 2016. Values of travel time in Europe: review and meta-analysis. Transport. Res. Pol. Pract. 94, 93–111.

Wardman, M., Ibáñez, J., Tapley, N., Vaughan, B., 2008. M6 Toll Study: Modelling of Passenger Choices. Prepared for the Department for Transport.

Wardman, M., Toner, J., Fearnley, N., Flugel, S., Killi, M., 2018. Review and meta-analysis of inter-modal cross-elasticity evidence. Transport. Res. Pol. Pract. 118, 662–681.

Waters, W.G., 1994. The value of travel time savings and the link with income: implications for public project evaluation. Int. J. Transport Econ. /Rivista internazionale di economia dei trasporti 243–253.

Wooldridge, J.M., 2010. Econometric Analysis of Cross Section and Panel Data. MIT press.

Zamparini, L., Reggiani, A., 2007. Meta-analysis and the value of travel time savings: a transatlantic perspective in passenger transport. Network. Spatial Econ. 7, 377.