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Using activity-based models and the capability approach to evaluate equity considerations in transportation projects

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Abstract
The capability approach (CA) is a theoretical framework that emphasizes the moral significance of individuals' capability to achieve outcomes that they value and have reason to value. It focuses on the actual opportunities that people have given their personal and social circumstances. This approach is grounded in the attempt to address fundamental deficiencies of the utilitarian approaches to welfare economics and to raise equity issues. In this work, we explore CA in the context of the transportation field. We develop a new measure, "Value of Capability gains" (VOC), designed to account for both efficiency and equity considerations as the key benefits taken into account in a Cost Benefit Analysis. We utilize activity-based models to assess travelers' capabilities under different transportation improvement scenarios. By using the activity-based accessibility measure to reflect individuals' abilities to reach alternatives that are potentially achievable, in accordance with the CA approach, the principle of diminishing marginal utility can be activated and applied to accessibility as a quantity of good or service—so that the more alternatives available to the traveler, the smaller the marginal benefit from an additional alternative. We use the VOC measure to examine different transportation scenarios in a simple synthetic case study, demonstrating that this new measure better accounts for equity.

Keywords Equity · Evaluation · Accessibility · Activity-based models · Capability approach · Cost-benefit analysis

Introduction

The capability approach (CA) emphasizes the importance of the opportunity to do things that people have reason to value (Sen 1985). It is largely based on Sen's critiques of traditional utilitarian approaches and opulence-focused approaches to welfare economics.

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Nevertheless, some scholars have viewed it as a generalization of the traditional approach to welfare economics (Anand et al. 2009). This approach has been recognized as a leading framework for considering and conceptualizing questions regarding social welfare, inequality, poverty, economic theory, and philosophy (Anand et al. 2011). However, the adaptation of CA for equity assessments and empirical applications in transportation has rarely been discussed.

Unlike traditional utility theories, CA focuses on *capabilities*—or capability sets—representing individuals' opportunities to achieve activities that a person can undertake.

Based on our former study, which suggests that the CA is more appropriate for the evaluation of transportation projects (Nahmias-Biran et al. 2017), in this paper, we suggest a new empirical measure that can reflect capabilities in the common evaluation approach (CBD), while emphasizing the benefits for individuals with less access.

As transportation is a fundamental determinant of opportunities that shape an individual's capabilities, and more specifically, accessibility is a prerequisite to realize capabilities, we suggest applying activity-based models to capture consumer capabilities. The activity-based accessibility (ABA) measure ("logsum"), the log of the denominator of this logit choice probability, gives the expected utility from a set of alternatives, and can be used to link different choices as in nested logit models. This measure is highly suitable for project evaluation as it expresses the consumer's benefits from all travel alternatives over the various dimensions, although it captures accessibility rather than capability.

Thus, the ABA is used in a different manner—it is calculated only for the individual's personalized choice set or capability sphere. The personalized choice set enables the distinction of travelers by accessibility levels. Accessibility is treated as a quantity of a good or service, and the principle of diminishing marginal utility can thus be applied. In accordance, the more alternatives that are available to the traveler, the smaller is the marginal benefit from another alternative. In this manner, the focus of the economic evaluation shifts from the value of time savings to travelers' capability levels, thus we incorporate equity considerations into the traditional evaluation. We develop a new measure, "Value of Capability gains" (VOC) designed to account for both efficiency and equity considerations as the key benefits in CBA.

The rest of the paper is structured as follows: "The capability approach" section describes the capability approach as a justice theory and its basic concepts. "The capability approach in evaluation" section provides the theoretical background on the capability approach in evaluation studies and in different fields, focusing on its relation and meaning in transportation studies. "Methodology" section presents the new evaluation measure suggested in this study. The fifth section comprises a case study and presents preliminary results based on the new measure. Finally, the last section summarizes the main conclusions and findings.

The capability approach

In developing his theory of social justice, Sen rejects the welfarist imperative that underlies utilitarianism and the resources approach. Instead, Sen underline, among others, Rawls' theory of justice. He thus draws on a notion that lies, as it were, between resources and welfare: capabilities. Sen describes capability as "our ability to achieve various combinations of functionings that we can compare and judge against each other in terms of what we have reason to value" (Sen in Beyazit 2011). Functionings are states of being and doing, i.e. activities that a person can undertake. A capability set represents a person's opportunities to achieve functionings. Thus, while "travelling" is a functioning, the opportunity to travel is an element of the individual's capability set (Dagsvik 2013). Sen's key point is that people differ fundamentally in their abilities to translate resources into functioning and capabilities. The capability set may be interpreted as the set of alternatives that are effectively available to the individual in the sense that she is able to use all of the options in the choice set according to her perception at a given point in time. Young car drivers, for example, have different capability sets compared to young individuals with no driver's license as their resources are different. However, two car drivers, a young person and a senior, will have different sets of alternatives that are effectively available to them due to their personal characteristics.

Capabilities are freedoms conceived as real opportunities (Sen 1985), valuable options or alternatives that exist not only formally or legally, but also effectively because they are available to the individual. A difficulty lies in measuring the actual capability set of a person, which largely depends on individual factors such as the available resources, a person's physical state, etc. In this context, Sen refers to "conversion factors", which represent the degree to which a person can transform resources into valuable functionings. The concepts of capability set and conversion factors can, in principle, allow accounting for non-preference information that is excluded by traditional utilitarianism (Dagsvik 2013). Nussbaum has further developed the CA. She construes the notion of "basic capability", which encompasses the set of capabilities needed for a minimally decent life (Nussbaum 2000). Following Nussbaum's suggestion to produce a list of functionings, the next challenge is to define a threshold level for each of these basic capabilities. Clearly, this is a major challenge. Sen leaves this question open and vaguely indicates that this level is to be decided by decision-makers and the wider public (Sen 1985). Above the threshold level for each capability, differences in the level of capability that people can attain do not signify an injustice—they do not change the fact that everyone does or does not enjoy equal basic capabilities. To obtain equal basic capability for everyone implies moving each and every person towards and beyond the threshold level for each of the capabilities that are specified to be necessary for a minimally decent or good enough life. So understood, the basic capability proposal falls in the family of sufficientarian ideals (Arneson 2002).

The capability approach in evaluation

The capability approach (CA) has been widely discussed in the literature (e.g. Anand et al. 2009, 2011). However, applying the CA in an empirical context presents a significant challenge, as Sen does not address empirical methodology. Various attempts have been made to operationalize the approach and produce a measure that offers a broader evaluative space than the one produced by utility-based measures. Health economists have been leading much of this pioneering work. Lorgelly (2015) offers a review of available CA-inspired economic evaluation measures, as well as applications to public health, physical and mental health, and social care interventions.

CA has further been adapted to education. For example, Boni et al. (2010) addressed the question of how universities can enhance international student capabilities to contribute to a fairer and more inclusive human development model. Lozano et al. (2012) explored the potential of the CA for higher education and discussed its synergism with the competence approach. Other adaptations and applications of the CA have been attempted in gender and poverty studies and in sustainability assessments (see for example, Halai 2011).

The capability approach in evaluating microdata studies

Although there is a large body of literature on CA, empirical studies based on microdata analysis are rather scarce (Dang 2014). Anand and van Hees (2006) suggested a way of measuring capabilities utilizing a questionnaire that aimed to distinguish between achievements (functionings) and capabilities. Anand et al. (2009) constructed an instrumental survey to identify capability indicators related to well-being and examined the influence of capabilities on life satisfaction (2011), introducing capability indicators to a model using data from the British Household Panel Study.

Burchardt and Le Grand (2002) proposed a method for assessing the extent to which the behavior of individuals is the result of constraints, focusing on employment capability and data from the Panel Study of Belgian Households. Bajmócy et al. (2014) examined the effects of technological change on welfare comparing utilitarianism and the CA approaches; they analyzed the correspondence of innovation capacity and welfare (well-being) situations in a Hungarian micro-regional data set. Gálvez-Muñoz et al. (2013) studied gender differences in children and adolescent well-being by using the CA and microdata from the Spanish Time Use Survey (2002–2003). Finally, Kaplan and Prato (2012) proposed a route-choice behavioral framework that accounts for individuals' spatiotemporal constraints by delimiting the master set, an approximation of known routes, to a consideration set—known routes that satisfy constraints related to travelers' latent traits and observable characteristics. While the motivation of this work was to capture a more realistic route-choice behavior, the use of travelers' characteristics to constrain the choice set and to create a consideration set is similar, in principle, to the attempt to capture travelers' real opportunities as a whole, i.e. capturing the capability set under the CA. As the methodology of computing the capability set is not the focus of this work, we will examine the importance of using the capability set from a project evaluation point of view and its implications for equity.

The capability approach in equity evaluation

In the field of education, Walker (2006) considered core ideas of capability and functioning, and demonstrated that these concepts can be operationalized by producing a provisional, situated list of education capabilities, with specific attention to gender equity in contemporary South African schools. Polat (2011) discussed the theoretical relationships between social justice and inclusion in education using the CA in Tanzania.

In health studies, Restrepo-Ochoa (2013) analyzed the contribution of CA to ethical reasoning in public health. Chilton et al. (2007) used CA and the human rights framework to address the non-proportional influence of the first 3 years of life on the developing child, focusing on the importance of early childhood nutrition and the detrimental effects of poverty and food insecurity on child development. Coast et al. (2008) questioned the implications of CA for health economics. Two specific issues were considered: the richer set of dimensions for evaluation provided by the CA (as opposed to health or utility), and the decision-making principle of maximization. Hocking and Townsend (2015) proposed a clinical and ethical decision-making framework, which can be used by physical therapy practitioners and facilitates the understanding and implementation of the CA for justice at the clinical level.

In sustainability research, Attias-Donfut (2013) analyzed specific characteristics of intergenerational outreach with notable reference to CA. Grasso (2007) described a comprehensive regional climate agreement for the South Pacific region using the CA, suggesting four domains of international distributive justice as well as the consequent criteria of equity. In poverty studies, an important contributions in putting CA into empirical work is that of Alkire, who proposed new methodologies for multidimensional poverty measures to supplement or replace official income poverty measures (see, for example, Alkire and Foster 2011; Alkire and Santos 2013, 2014; Alkire et al. 2013).

In the transportation field, the adaption of the CA in general as well as for equity studies is still at its early stages. Beyazit (2011) suggested that social justice norms in transport should be examined by engaging the CA alongside with existing methods. Hickman et al. (2017) demonstrate how the theoretical framework of the CA can be used to assess what transportation services individuals might be able to access using surveys in low- and high-income neighborhoods in Manila, the Philippines. Smith et al. (2012) focused on transport for rural households in terms of affordability and adequacy, and framed their discussion in terms of transport disadvantage and the CA. Wismadi et al. (2014) examined whether the inclusion of spatial neighborhood comparison factors in Preference Modelling (the procedure in which preference values from stakeholders are transformed into sets of priorities) allows spatial decision support systems to better address spatial equity. They introduced the concept of Spatial Preference Modelling and applied the CA, defining opportunity to mobilize as a non-income indicator. Martens (2016) used the CA to explain how accessibility captures a person's capabilities, and the reason why Sen and Nussbaum, the major proponents of the CA, make the case that evaluation of policy interventions should primarily focus on capabilities rather than functionings. As justice theories have an expression in practice, their discussion is essential to the integration of equity considerations into economic evaluation. Since this topic justifies a complete discussion of its own, we rely on Nahmias-Biran et al. (2017), which provided an overview of the conceptual quintessence of justice theories and their consequences for transport project appraisal. They presented CA alongside other theories of justice, and discussed the implications for transport evaluation. This work laid the theoretical foundation for developing the activity-based capability tool presented in this paper.

Equity considerations in transport project evaluation

Cost Benefit Analysis (CBA), which became the accepted standard in transportation project evaluation, is limited in its ability to account for equity considerations. CBA does not enable reflection on welfare gains or losses of specific groups or people. Therefore, in public practice, the expected impacts of transportation (and land-use) improvements are examined by comparing impacts across segments in the population. However, comparing mean benefits may mask important individual level outcomes (Bills and Walker 2017). The use of activity-based models can overcome this limitation as they provide better understanding of travel behavior at the individual level compared to traditional modeling, which is usually applied in an aggregate way.

CBA can also potentially lead to an optimism bias which favors higher income groups, stemming from the way the demand models are used. This bias is associated with time savings, and with the way in which the monetary value of these savings is calculated.

Monetized travel time benefits are determined through Willingness to Pay (WTP), and thus vary with income. The implications of using WTP values are that transport investments primarily benefit higher income groups (for a thorough discussion, see Nahmias-Biran and Shiftan 2016). The ‘‘equity value of travel time” value was meant to correct the bias inherent to CBA and is used in most countries that utilize CBA. This value is based on an average income level and applies for all travel time savings, independent of the income level of the traveler (Hayashi and Morisugi 2000). Although it promotes equity to some extent, it leads to bias estimation of the benefits. A way to overcome this bias is to break the connection between travel time savings and benefits, which ABM fails to do, despite its advantages. In this work, we attempt to overcome problems associated with CBA and tailor it to be equity-oriented.

Applying the capability approach to transportation

Transportation benefits are manifested as the possibilities that transportation infrastructures and services offer for travel and access (Martens 2012). They are the means to reach the opportunities that shape people's capabilities. Accessibility indicates the ability to accomplish a broad range of actions by linking individuals to places and people that are set apart in space and time; accessibility is therefore a strategic dimension for consumers' capabilities. Accessibility captures the relationship between transportation infrastructures, activities, and land uses, and corresponds directly with the perceptions of users of the transportation system (Martens 2012; Nahmias-Biran and Shiftan 2016; Dong et al. 2006).

Capabilities depend not merely on resources but rather on the interaction between resources and personal characteristics. Therefore, fairness requires a measurement of accessibility which reflects particular features of a person that shape its ability to translate a resource into a capability (Martens 2012).

CA thus provides two important insights for the distribution of accessibility. First, accessibility should be distributed in such a way as to guarantee individuals with sufficient level of capabilities (many of which, but not all, can be linked to actual, physical destinations). Second, accessibility should be measured considering the particularities of individuals as much as the characteristics of the transport and land use systems (Nahmias-Biran et al. 2017). For this reason, activity-based models (ABM) are most suitable for evaluating individuals' capabilities in the context of transport systems (Nahmias-Biran and Shiftan 2016; Dagsvik 2013) and has a clear advantage for equity analysis (Bills et al. 2012).

ABM models are based on the concept of Day Activity Schedule (DAS), modeling an entire day's schedule of multiple activities and trips. This class of models treats travel as being derived from the demand for personal activities. These models capture the entire picture of individuals' opportunities, accounting for trade-offs among various activities and travel alternatives in one's daily activity pattern. The importance of ABM lies in its capacity to realistically capture people's travel and activity behaviors. As ABM models are estimated at the disaggregate level, they provide better understanding of travel behavior at the individual level. Thus, ABM models provide a good basis to develop more appropriate accessibility measures. As an alternative to combining the CA approach and ABM, it is possible to apply the capability approach to the 4-step process. However, this latter approach will fail to address individuals' capabilities.

The activity-based accessibility measure (ABA) can be obtained from the DAS model system and enables studying the effects of personal choice sets. It captures the relative attractiveness of various alternatives and reflects not only the nature of land use and properties of the transportation system, but also the socioeconomic characteristics of individuals (Dong et al. 2006). The ABA measure allows one person to have different accessibilities for different choice situations, depending on her characteristics. As a result, ABA is highly suitable for project evaluation, as it expresses the consumer benefits and encompasses the evaluation of equity as Sen perceives it (Nahmias-Biran and Shiftan 2016). Along with its benefits, similar to the traditional approaches, the ABA measure identifies the same number of alternatives for different people and is also biased towards higher income groups, as it is dominated by the Value Of Time (Nahmias-Biran and Shiftan 2016).

The activity-based capability (ABC) measure, calculated using the ABA measure, can overcome ABA's weaknesses and reflect people's abilities to reach only those alternatives that are potentially achievable.

Methodology

This paper presents a framework of a single measure encompassing both efficiency and equity considerations. This innovative measure is based on ABM and considers the heterogeneity in passengers' preferences, as well as their basic level of accessibility. The suggested measure was designed to reflect key elements of the CA, as well as to serve as a key measure in Cost Benefit Analysis (CBA).

Activity-based models (ABMs) have two important implications for realizing the CA, which have not been studied before. First, since ABMs are fully disaggregate-models simulating activity and travel patterns for each individual separately, they allow analysis by various groups of the population. Second, ABMs can be used to generate the ABA measure, offering an estimation of the overall benefits from transport investments and policies. The ABA measure allows individuals to have different accessibilities for different choice situations depending on their characteristics; however, it identifies the same number of alternatives for different people.

The CA requires that only the alternatives that are effectively available to the individual will be evaluated. This requirement necessitates defining a criterion for effectively available alternatives, such as a threshold of travel time (which may vary by trip purpose, individual characteristics, or any other criteria). By evaluating alternatives that are effectively available to the individual, the principle of diminishing marginal utility can be applied to accessibility as a quantity of good or service. As can be seen from Fig. 1, taken from Martens (2006), travelers with initial low levels of accessibility will gain more from an additional unit of accessibility compared to travelers with initial high levels of accessibility. As more alternatives become available to the traveler, the marginal benefit from each additional alternative decreases.

Appling the criterion which takes only the effectively available alternatives, we thus use the ABA measure in a manner which reflects people's abilities to reach alternatives that are potentially achievable, unlike classical activity-based accessibility indictors that consider all opportunities within the network. Notably, Sen does not address empirical questions such as how actual capabilities can be measured and how defining potentially achievable activities can technically be performed in several ways, representing different interpretations of Sen's terminology. While this is a central issue for the realization of CA, it is not the focus of this work. We rather focus on how the traveler's limitations affect her realistic choice set, and the way this choice set should be evaluated. Accessibility is a prerequisite to realize a person's

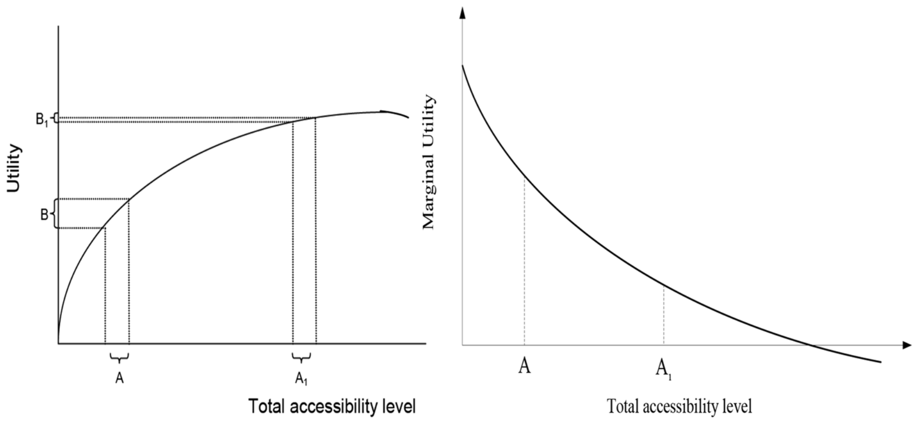

Fig. 1 The principle of Diminishing Marginal Utility applied to accessibility gains. Travelers with initial low levels of accessibility will gain more (B) from an additional unit of accessibility (A) than travelers with initial high levels of accessibility, who will receive lower improvement in their utility (B1) for the same improvement of accessibility (A1). (*Source*: Martens 2006)

capabilities, and by considering the change in ABA at the top of the hierarchy, and including only alternatives that enhance the traveler's capabilities, we obtain an alternative measure for consumer benefits—the consumer capability. To obtain a measure of the actual capability, we apply conversion factors and functions on the choice set (see Dang 2014).

The Consumer Capability measure, suggested in this paper, has a similar mathematical expression to the Consumer Surplus (CS) captured by the logsum, with an important difference—it is calculated only for the customized choice set, i.e., for the capability sphere of each individual. Thus, the Consumer Capability measure can be significantly altered by accessibility gains of the least accessible population and no longer reflects the CS, but rather the Consumer Capability. Aggregating consumers' capabilities together we yield an aggregated measure—the "Value of Capability gains" (VOC). This new measure is the basis of our evaluation, serving as the key benefit considered in the CBA.

Using a simple synthetic case study, we demonstrate the use of the VOC measure under different transportation scenarios, and analyze how the new measure performs as a measure of equity. Namely, we examine the distribution of benefits according to different accessibility levels before and after applying different policies, comparing the VOC measure to the traditional method. We analyze the aggregated results, i.e., the total differences in consumer capabilities obtained by the VOC and compare them to those obtained by the traditional measure.

Theoretical framework

According to Sen's capability approach, life is seen as a set of functionings, which could be described as different aspects of life. In the context of transportation, the basic element of an individual's functioning is traveling. We follow the vector of functionings which has been formalized by Sen (1985) and discussed by Binder and Broekel (2011), adapting it to exclusively describe travel functioning:

$$\vec{b} = f_n\left(d\left(\vec{j}\right)|\vec{Z}_n, \vec{Z}_s, \vec{Z}_e\right) \tag{1}$$

where $\vec{j}$ is a vector of alternatives out of the set of all possible alternatives J. $\vec{j}$ is mapped into the space of characteristics via the conversion function d so that $d(\vec{j})$ is a characteristics vector of a given alternatives vector $\vec{j}$. The characteristics of potential alternatives do not vary across individuals. What does vary, however, is the way individuals can benefit from these characteristics. This is reflected by the conversion function of individual n, f_n, that maps a vector of characteristics into the space of functionings. This conversion is influenced by the conversion factors, which are divided according to type—individual ($\vec{Z}_n$), social ($\vec{Z}_s$), and environmental ($\vec{Z}_e$) influences, and these are endogenous constraints.

The set of all feasible functioning vectors for individual n is this person's capability set, Q_n. It represents the person's opportunities to achieve well-being, reflecting the various functionings that are potentially achievable given her constraints $J_n, \vec{Z}_n, \vec{Z}_s, \vec{Z}_e$. This set can be defined as:

$$Q_n(J_n) = \left\{ \vec{b}_n | \vec{b}_n = f_n\left(d\left(\vec{j}_n \right) | \vec{Z}_n, \vec{Z}_s, \vec{Z}_e \right) \right\} \tag{2}$$

Equally, we can limit the number of opportunities recognized by the model to create the individual's n capability set.

Out of this person's capability set, the expected value of the individual's maximum utility across potentially achievable travel alternatives can be estimated using the activity-based capability (ABC) measure:

$$\frac{1}{\mu} \ln \left(\sum_{j=1}^{Q_n(J_n)} e^{\mu V_{nj}} \right) \tag{3}$$

where V_{nj} is the modeled utility that traveler n obtains from alternative j ($n = 1, 2, \ldots, N$; $j = 1, 2, \ldots, Q_n(J_n)$). μ is a scale parameter. This formula clarifies that utility is not associated with utilitarianism, but rather a mathematical expression of what a person has a reason to value, and it is used as a tool to express the main principles of the capability approach.

If ABC_n^0 denotes the accessibility value for traveler n taking into account potentially achievable activities before implementing any transportation policy, and ABC_n^1 denotes the same measure after implementing the transportation policy, then the value of the capability gain from the policy, in utility units, is:

$$\Delta ABC_n = ABC_n^1 - ABC_n^0 \tag{4}$$

If we have utility functions of the form:

$$V = c \cdot C + t \cdot T + \ldots \ldots \tag{5}$$

where C is the cost in dollars and c is the cost coefficient estimated by the model, then ABA can be monetized and used as an expression for the consumer surplus (De Jong et al. 2005). Thus, the value of the capability gain from the policy for achievable activities, the ABC, can also be monetized and used:

$$\Delta CC_n = \Delta ABC_n / \sum P_j c_j \tag{6}$$

where P_j is the weight of the population that chooses j.

Considering the change in the sum of all ABCs calculated at the top of the hierarchy, we can express consumer benefits from choosing potential realistic activities in monetary terms, obtaining the "Value of Capability gains" (VOC):

$$VOC = \sum_{n=1}^{N} \left(\Delta ABC_n / \sum P_j c_j \right) \tag{7}$$

We thus obtained a single value in monetary terms that can be integrated into CBA—replacing the traditional measure. Figure 2 summarizes the methodology, emphasizing the differences between the suggested measure and the ABA. Note that the change in the ABC calculation process as compared to ABA is not only technical but conceptual. It makes travel time savings less important in cases where the basic accessibility is low, magnifying the accessibility gain of these individuals.

Note that the capability approach implementation to transportation can be understood in the terms that Nussbaum suggested—producing a list of functionings that supposedly reflect a common consensus of what is valuable (Nussbaum 2000). In practice, a

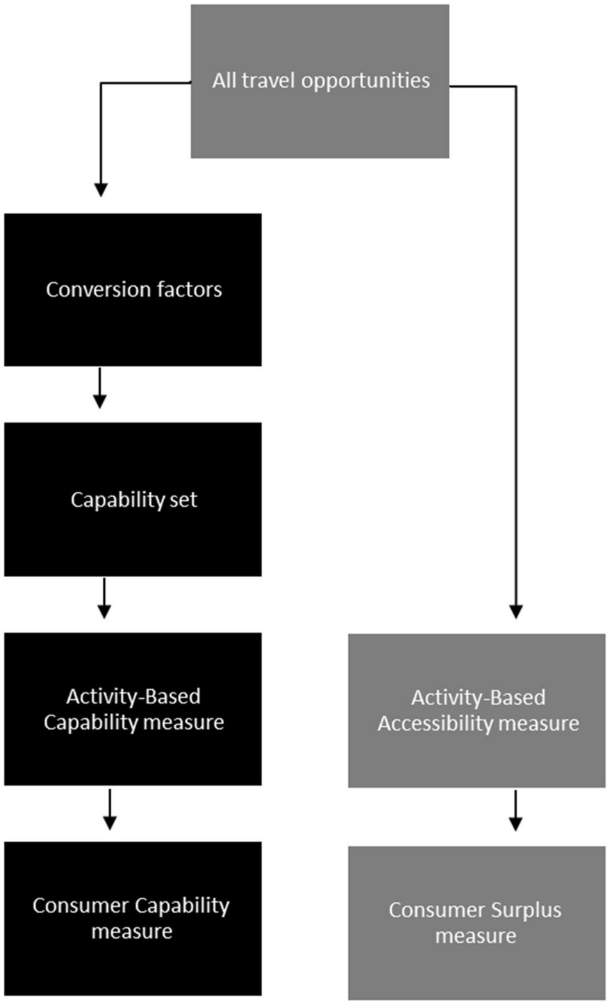

Fig. 2 Consumer capability calculation process. Consumer capability in black versus consumer surplus calculation process in gray

set of essential destinations which are a part of a person's functioning should be defined within the model and Eqs. 4–9 should be calculated only for those destinations.

Case study: destination and mode choice model

For demonstration, the suggested methodology was used with a simple synthetic activity-based model, accounting for destination and mode choice. For simplicity, we did not assess the benefits from a full ABM, but rather focused on the benefits obtained from changes in the two main choices dimension—destination and mode—resulting from some transport project. This can be easily extended to a full activity-based model, but would complicate the presentation. For simplicity and clarity of presentation, we keep it to a simple nested logit of these two dimensions, as shown in Fig. 3. At the upper level of this model, each individual chooses a destination among 12 possible alternatives, and at the lower level she chooses the mode used to reach this destination (car or bus). In our case study, destinations represent employment opportunities. Destinations 1 and 2 are located within the central business district (CBD), which is characterized by high employment density. All other destinations are located outside the CBD.

For a preliminary examination, we chose a sample of two representative passengers—one "rich" passenger and one "poor" passenger. At the lower level, we assumed a simple synthetic binary logit mode-choice (Eqs. 8–11), and at the upper level a synthetic binary logit destination choice (Eq. 12) as follows:

$$\text{For the "poor":} \begin{cases} V^j_{bus} = -0.04T^j_{bus} & (8) \\ V^j_{car} = -0.04T^j_{car} + 0.2A & (9) \end{cases}$$

$$\text{For the "rich":} \begin{cases} V^j_{bus} = -0.02T^j_{bus} & (10) \\ V^j_{car} = -0.02T^j_{car} + 0.2A & (11) \end{cases}$$

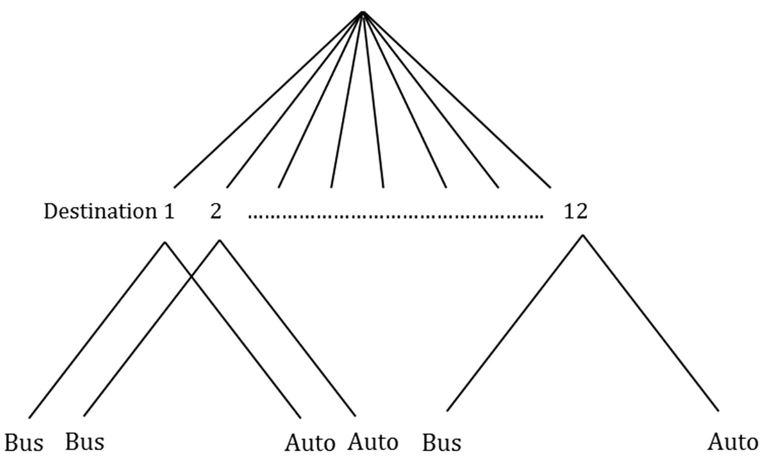

Fig. 3 Model structure. Our case study consisted of 12 possible destinations and 2 possible modes for each destination (car or bus)

$$\text{For the ``poor'' and for the ``rich'':} \quad V_j = 0.8LS_j + 0.00003EmpDen_j \tag{12}$$

where T_i^j is travel time in minutes to destination j by bus/car, A is the number of vehicles in the household, LS is the accessibility measure (logsum) from the mode-choice model, and $EmpDen_j$ is the employment density in the destination j (j = 1, 2, …, 12).

To reflect variability in passengers' behaviors, time coefficients were synthetically set to reflect the value of time for the two populations: high time coefficient (0.04) for the "rich" and low time coefficient (0.02) for the "poor". The number of vehicles in the household was synthetically set to reflect differences between the "rich" and the "poor", so that the "rich" have three vehicles in the household while the "poor" have only one vehicle. These sectors also vary in their basic level of accessibility to various work activities. The lower level of accessibility for the poor is expressed in longer travel times—43 min on average by car, and 110 min on average by bus. For the rich, however, we assumed shorter travel times to all destinations—24 min on average by car, and 86 min on average by bus (Table 1). Travel time by car and bus, as well as employment density in the destinations, reflected real data as obtained from the Tel Aviv activity-based model. We recognize that our classification of "rich" and "poor" is not realistic, and in reality, what makes people "poor" or "rich" in terms of access to transport is a complex combination of different characteristics and circumstances. In addition, the assumption that the "poor" is characterized by long travel time, and the "rich" is characterized by high number of vehicles in the household, in general, holds for the Tel Aviv metropolitan area, although in other cities these assumptions may not hold. At the same time, for the purpose of a clear and simple demonstration of the methodology, these characteristics were selected. While this network is synthetic, and our calculations were conducted analytically on a small synthetic sample, the two passengers can be taken to represent a much larger population.

Destination utility function was defined identically for both populations and includes the accessibility measure (logsum) from the mode-choice model and the employment density in the destination. The utilities were calculated for each individual and were used to calculate the probability of choosing different destinations under different modes. The ABA, which is an overall accessibility measure obtained at the top of this model, was calculated only for those work destinations that were within travelers' realistic range of use (30 min ride by all modes), therefore reflecting the ABC. This imitates a simplified conversion factor, translating opportunities as a resource into actual abilities (Bertolini et al. 2005; Kenworthy and Lanbe 1999; Prud'homme and Lee 1999; Wiel 2002; Schwanen and Dijst 2001). Note that this simplified and uniform conversion factor is used for demonstration only. Future work is required to develop a conversion factor which will reflect the various functionings that are potentially achievable given individuals' personal, social, and environmental constraints.

Table 1 Case study variables

Person	Value of time ($/h)	Number of vehicles	Average travel time by bus (min)	Average travel time by car (min)	Basic level of accessibility
"Rich"	60	3	86	24	2.26
"Poor"	30	1	110	43	2.13

Transportation project scenarios

Three hypothetical transportation project scenarios were tested. The first one simulates public transport improvement, by assuming a 35 min reduction in travel time for destination 2 (located within the CBD). The second scenario simulates road infrastructure improvement for private transport only by assuming a reduction of 10 min in travel time for destination 1 (located within the CBD). The third scenario simulates a development of a BRT line by assuming a 70 min reduction in travel time for destination 4, which is a remote destination (located outside of the CBD).

We applied our synthetic model to estimate destination and mode choice changes resulting from each of these three policies. We estimated the consequent changes in consumer benefits by calculating the ABA differences for each passenger (see Fig. 4a). Then, we calculated the ABA differences for each passenger for realistic destinations only (up to 30 min

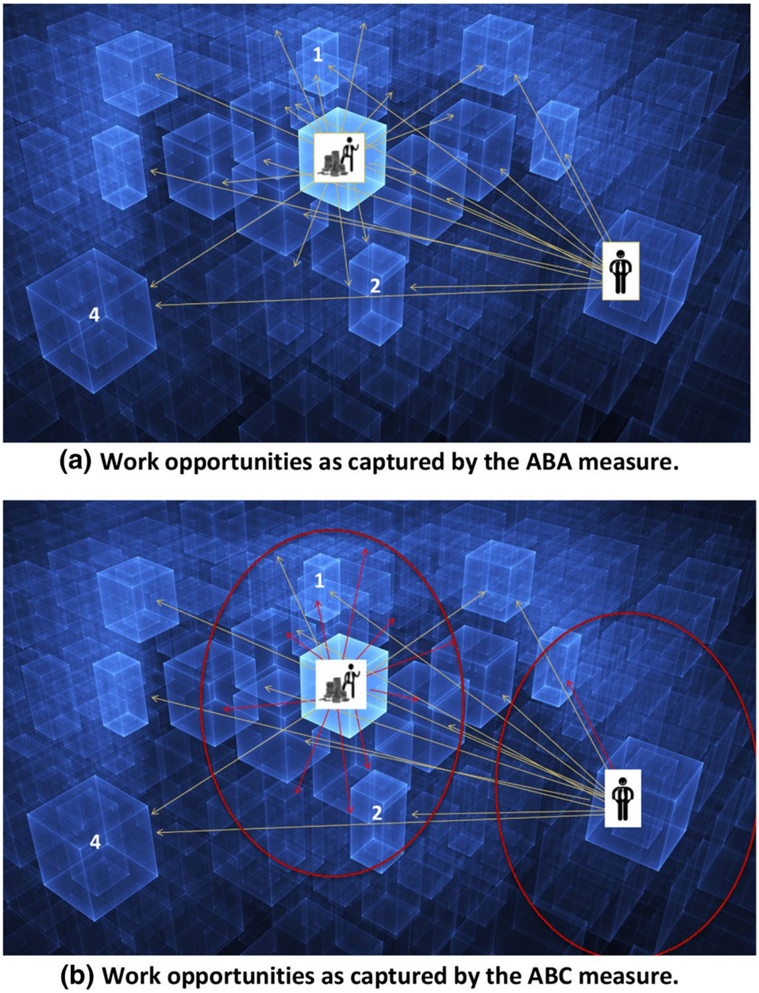

Fig. 4 Work opportunities as captured by the **a** ABA measure, **b** ABC measure

ride) (see Fig. 4b). Note that we assumed the same threshold for different passengers for the simplicity of this example only. In principle, the thresholds are highly individual and can be defined as a function of personal characteristics. The decision rule renders the ABA as an activity-based capability (ABC) measure. Finally, we divided ABC differences by the cost coefficient, obtaining consumer capability. The aggregation of this measure yields the new measure, "Value of Capability gains" (VOC), which reflects the total change in consumers' capability where the main benefit is the change in accessibility. For comparison purposes, we calculated the change in consumers' surpluses also using the traditional method. The traditional method refers to the consumer surplus as calculated by using the rule of half or by the ABA; in both approaches we expect to get approximately the same result.

Results and discussion

In the base state, before applying any transport policy, according to her conversion rule the "rich" passenger can reach 10 destinations out of 12. In contrast, the "poor" can reach only one achievable destination out of 12. Table 2 presents the overall changes in consumer benefits from the three scenarios in utility terms, using two different measures, the ABC and the ABA. The ABC incorporates the VOC, thus it is sensitive to the number of accessibility gains given the number of destinations the passenger can reach. The ABA, on the other hand, reflects the traditional approach in which benefits are largely determined by the value of time.

The results indicate that for the first scenario, which included a reduction of 35 min in travel time by bus, the change in consumer benefit using the ABC is 30 times larger for the poor compared to the rich. Travel time was reduced also for the rich, but no additional destination was gained for the rich, while the poor gained an additional affordable destination. Given that the poor traveler had only one achievable destination at the base state, the addition of a single target to the choice set is highly significant, as reflected in a large benefit gain (1.068). On the other hand, for the same scenario and for the same improvement, the change in consumer benefit using the ABA is 2.38 times larger for the rich than for the poor due to higher time values for the rich, which is reflected in a higher time coefficient and the fact that the ABA considers all 12 opportunities as available for both the poor and the rich.

Table 2 Changes in consumer benefit using the ABC and the ABA as a main measure—a comparative summary

Scenario	Number of available destinations		Total change in consumer benefits			
	"Poor"	"Rich"	"Poor"	"Rich"	"Poor"	"Rich"
Base	1	10				
Scenario 1: 35 min in bus time	2	10	0.013	0.031	1.034	0.034
Total scenario			0.044		1.068	
Scenario 2: 10 min in car time	1	10	0.050	0.121	0.000	0.139
Total scenario			0.171		0.139	
Scenario 3: 70 min in bus time	2	11	0.001	0.015	0.784	0.064
Total scenario			0.016		0.848	

The results for the second scenario of car time reduction show that the benefits measured by the ABC are 0.139 for rich and 0 for the poor. These results imply time saving for the rich only; however, neither the rich nor the poor gain additional destinations. Conversely, the change in consumer benefit using the ABA is 2.4 times larger for the rich than for the poor due to higher time values for the rich.

For the third scenario, which simulates the addition of a BRT line to a selected remote destination, benefits measured by the ABC are more than 12 times larger for the poor than for the rich. This is due to a destination gain for the poor. While the rich traveler also gained an additional destination, the benefit change is smaller due to the high level of opportunities for the rich at the base state. Using the traditional method, however, we receive the opposite—more than 15 times larger benefit for the rich than for the poor—again, due to higher time values for the rich, and the lack of differentiation by the number of alternatives available for the traveler.

Focusing on the aggregated results, for the ABC measure the bus line improvement provides 7.7 times more benefits than the car investment scenario. The BRT line improvement provides 1.25 times more benefits than the car investment scenario, showing a clear preference for public transport alternatives. In contrast, according to the ABA measure, private transportation infrastructure investment provides 10 times the benefits of the BRT line improvement scenario and 3.8 times the benefits of the bus line improvement scenario, indicating a clear preference for investments in private transport.

Our results demonstrate that the ABC measure is sensitive to accessibility improvements given traveler's constraints, favoring the poor when using an accessibility-based measure under the CA. When using the ABC the total estimation of the project is mainly determined by gaining additional capabilities for the less accessible population. In contrast, estimations under the traditional method are mainly sensitive to time savings and favor the rich. These trends are apparent both in same group results and at the summed (total) results.

Conclusions

The capability approach has the potential to provide a more equitable evaluation of transport projects, as it is derived from the actual opportunities that people have given their personal and social circumstances. This study is the first to suggest a practical way to use the CA in transport project evaluation by estimating the "Value of Capability gains" (VOC) as the key benefit taken into account in CBA. This new measure relies on the activity-based capability (ABC) measure and is calculated given each person's capability set. This application of the CA, based on the VOC measure, has the advantage of evaluating a project through a single measure and, at the same time, capturing the heterogeneity in individuals' activities and capacities. The single measure integrates equity considerations into the CBA, therefore representing both efficiency and equity considerations.

This paper explores transportation benefits from the consumer perspective, not accounting for investments costs—which are independent of the way we calculate the benefits, and therefore identical. The VOC measure builds upon activity-based models that can represent key aspects of the CA. First, these models have the ability to simulate activity and travel patterns for each individual. Second, they allow using the activity-based accessibility measure to estimate the overall benefits from transport investments and policies. By evaluating only the set of alternatives that are effectively available to the individual, as the CA implies, the principle of diminishing marginal utility can be activated and applied to accessibility as the quantity of good or service.

A simple case study was explored, and the results obtained using the new measure were significantly different than those obtained using the traditional measure. These differences justify deviation from the traditional CBA in order to promote equity in the allocation of investments. Estimations under the VOC are mainly influenced by gains of additional capabilities for the less accessible population, which is more sensitive to accessibility improvements given travelers' constraints. The new measure is expected to give better assessments of peripheral projects, for which the economic benefits under CBA are often questionable. One example is the Rail to Beit Shean (Israel's Valley Railway), which cost the Israel Government 4 billion NIS. While the overall time saving calculated for the expected demand using the traditional evaluation was not significant, it did provide accessibility to new areas and connected the main northern metropolitan area of Haifa to the valley cities, a population that so far had little accessibility. These kinds of projects are expected to score higher with VOC, as they serve to enhance the accessibility of low accessibility consumers who live in the periphery. Estimations under the traditional methods, on the other hand, are mainly sensitive to time savings and favor the rich.

Another important advantage of the suggested measure lies in the fact that it is possible to take into account all the decision dimensions and tie them together. Our simplified example focuses on mode and destination choices only, but can be easily expanded, at some computational cost, to more real world situations where there are more individuals who make more types of choices. For example, it is possible to add a time of day choice dimension, intermediate stop dimension, etc. Thus, we can consider different constraints for different choice dimensions and sum them together to get the VOC. The idea is to consider all of the individual's constrains and calculate the capability set of each dimension. Having discussed the advantages offered by the new evaluation approach presented in this study, we would like to address issues that require further examination and investigation. Individual differences in converting resources into functionings in the form of "conversion factors" have been stressed by many theoretical studies on the CA. Conversion factors are notoriously difficult to capture empirically and have not been studied at all in transportation. Therefore, a thorough investigation of this topic is required, possibly with questionnaire design methods. Such an investigation would allow the examination of key elements of Sen's theory of capabilities in transportation such as how far people willing are to travel to fulfill various desires and needs, how well people use different options and activities, and personal, environmental and social barriers they face accessing various activities, etc.

Another issue is the conversion of benefits into monetary terms. The translation of ABCs into monetary terms can disrupt the gaps in benefits which are obtained using the new measure. Therefore, the transition should be carried out with the model estimation using the cost coefficient, as proposed in our previous work (see Nahmias-Biran and Shiftan 2016). The cost coefficient is used as an equivalent for the marginal utility of income, and this procedure allows the preservation of the gap in benefit.

Further work is needed to make the newly proposed measure operational, and to fully test its effectiveness and potential contribution. Future studies will be required to address the various limitations and questions mentioned above, and most importantly to explore ways of translating sets of opportunities or alternatives into sets of capabilities. Spatial preference modelling could allow accounting for population heterogeneity and promote the ability to capture individuals' sets of capabilities. A possibly application of the CA approach which is derived from the ABA could provide different results in evaluating transport projects, possibly with greater emphasis on equity issues, and future work may explore some hybrid approaches to using them in parallel. For example, Wang et al. (2014) considered integrated transport planning with a hybrid approach of utility and regret. Finally, our approach should be further examined on a full activity-based model, real data, real models, and a wider range of policies and investment scenarios. Such research will allow concluding whether replacing the traditional approach of evaluation, which is based on the value of time savings, with the newly suggested approach of using the value of capability gains indeed contributes to the promotion of equity considerations in transport policy-making.

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