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Diagnosis of cause-effect relationships in gender mobility in large Brazilian cities

Diagnóstico das relações causa-efeito na mobilidade por gênero em grandes cidades brasileiras

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Recebido:
19 de julho de 2021
Aceito para publicação:
9 de abril de 2022
Publicado:
30 de abril de 2022
Editor de área:
Antônio Nélson Rodrigues da Silva

Keywords:
Gender mobility.
Causal inference.
Structural equation modeling.

Palavras-chave:
Mobilidade por gênero.
Inferência causal.
Modelagem de equações estruturais.

DOI:10.14295/transportes.v29i3.2662

ABSTRACT
Despite recurrent efforts to characterize the different patterns of mobility by gender in the North and Global South, the causal relationships that determine this phenomenon are still unclear. This article seeks to explain the part of these differences that stems from the sexual division of labor, through confirmatory quantitative analyses. Based on a conceptual representation of the problems built upon the literature, a causal diagram was constructed which translates the cause-effect hypotheses of interest and controls the possible sources of confounding. Data from the São Paulo OD survey were used in the estimation of structural equation models, which confirmed causal explanations based on three key elements: household assignments, professional insertion, and accessibility. Evidence was found that the social impositions arising from the sexual division of labor impact on trip production and time budget limitations, with heterogeneous causal processes being observed not only between genders but also among income groups.

RESUMO
Apesar dos recorrentes esforços de caracterização dos distintos padrões de mobilidade por gênero em metrópoles do Norte e Sul Global, ainda são pouco claras as relações de causalidade que determinam esse fenômeno. Este artigo busca explicar a parcela dessas diferenças que decorre da divisão sexual do trabalho, apoiando-se em análises quantitativas confirmatórias. Partindo de uma representação conceitual da problemática advinda da literatura, construiu-se um diagrama causal que traduz as hipóteses causa-efeito de interesse e controla pelas possíveis fontes de endogeneidade. Dados da pesquisa OD de São Paulo foram utilizados na estimação de modelos de equações estruturais, que confirmaram explicações causais baseadas em três elementos-chave: atribuições do lar, inserção profissional e acessibilidade. Evidenciou-se que as imposições sociais decorrentes da divisão sexual do trabalho repercutem na produção de viagens e nas limitações sobre o orçamento de tempo, sendo observados processos causais heterogêneos não só entre os gêneros, mas entre classes de renda.

1. INTRODUCTION

The sexual division of labor, characterized by the assignment of the productive sphere to men and the reproductive sphere to women, is pointed out as the main determinant of differences in mobility by gender (Kergoat, 2003; Peters, 2001). While there are positive aspects to women's mobility patterns, as they stand out as more environmentally and economically sustainable behaviors (CIVITAS, 2014; Miralles-Guasch *et al.,* 2016), inequalities between female and male mobility may represent a type of social exclusion (Duchène, 2011; Lecompte and Juan

Pablo, 2017) that negatively impacts women's access to jobs and other opportunities offered in urban spaces. Investigating the causal relationships that determine this phenomenon allows a better assessment of how public policies can have differential impacts on the problem of mobility by gender.

For decades, studies undergone in the context of developed countries have pointed to evidence of differences in mobility levels and patterns between women and men (Hanson and Johnston, 1985; Prashker *et al.,* 2008; Scheiner and Holz-Rau, 2017). Such distinct mobility behaviors have been corroborated in some studies focused on large cities in the Global South (Srinivasan and Rogers, 2005; Venter et *al.,* 2007; Svab, 2016; Macêdo *et al.*, 2020). Beyond noting the differences, several research efforts have investigated their origins and determinants (Gonzalez *et al.,* 2020; Hanson, 2010); however, there have been few efforts to effectively measure the causal relationships explaining this phenomenon (Fanning Madden, 1981; Gimenez-Nadal and Molina, 2016).

Considering the relevance of this problem in the context of Brazilian metropolises (Macêdo *et al.,* 2020), this work sought to contribute, from a methodological and phenomenological point of view, to the investigation of cause-effect relations, that is, to the diagnosis of problems inherent to the condition of female mobility, arising from the sexual division of labor. To this end, we initially proposed a conceptual representation of the problem of inequalities in mobility by gender, based on a review of the literature on this phenomenon in developed and developing countries (Section 2). Then, a causal diagram was constructed, explaining the hypotheses to be investigated about this problem (Section 3). In Section 4, data and analysis methods applied to the case study in a large Brazilian city are described; with the results of the diagnosis of causal relations being discussed in Section 5. Finally, Section 6 highlights the conclusions and main contributions of this pioneering effort of causal inference of the determinants of mobility by gender in Brazil.

2. THE PROBLEM OF GENDER INEQUALITIES IN MOBILITY PATTERNS

Studies of urban mobility by gender have shown differences in trip patterns between women and men, pointing to the sexual division of labor as an exogenous cause of these differences (Kergoat, 2003), resulting from gender inequalities in household responsibilities (roles), employability, and income (Table 1) in the Brazilian context. It is argued that these inequalities result from a productive (valued) sphere assigned to men and a reproductive (devalued) sphere assigned to women, reflecting in distinct levels and patterns of mobility.

Table 1 – Participation by gender in the Brazilian labor market (Pinheiro *et al*., 2009)

Indicator	Women	Men
Participation in the labor market (2009)	68,9%	81,6%
Unemployment rate (2009)	10,2%	6%
Average monthly income	66%	100% (reference)
Paid weekly working hours (hours)	35,6	42,9
Unpaid weekly working hours (hours)	19,7	4,8
Total weekly working hours (hours)	55,3	47,7

In general, international and Brazilian research efforts show common results regarding differences in associative patterns of mobility by gender (Peters, 2001; Rosenbloom, 2006; Rosenbloom and Plessis-Fraissard, 2010; Svab, 2016; Macêdo *et al.*, 2020). These studies

describe that women have mobility patterns more affected by the presence of children in the household (Srinivasan and Rogers, 2005; Svab, 2016), which leads them to make more trips for reasons other than work (shopping, health, carrying passengers). This requires them to make larger amounts of trips compared to men, but over shorter distances (Crane, 2007; Rosenbloom, 2006). From this greater variety of trip purposes derive a greater diversity of origins and destinations (Rosenbloom and Plessis-Fraissard, 2010). Because of time budget constraints, their trips are more chained, combining diverse travel needs into single journeys (Root and Schinder, 1999). However, despite these time constraints, there is a higher use of public transport and walking trips by women (Srinivasan and Rogers, 2005; Svab, 2016; Macêdo *et al.*, 2020) which partially explains both the chaining and the shorter distances.

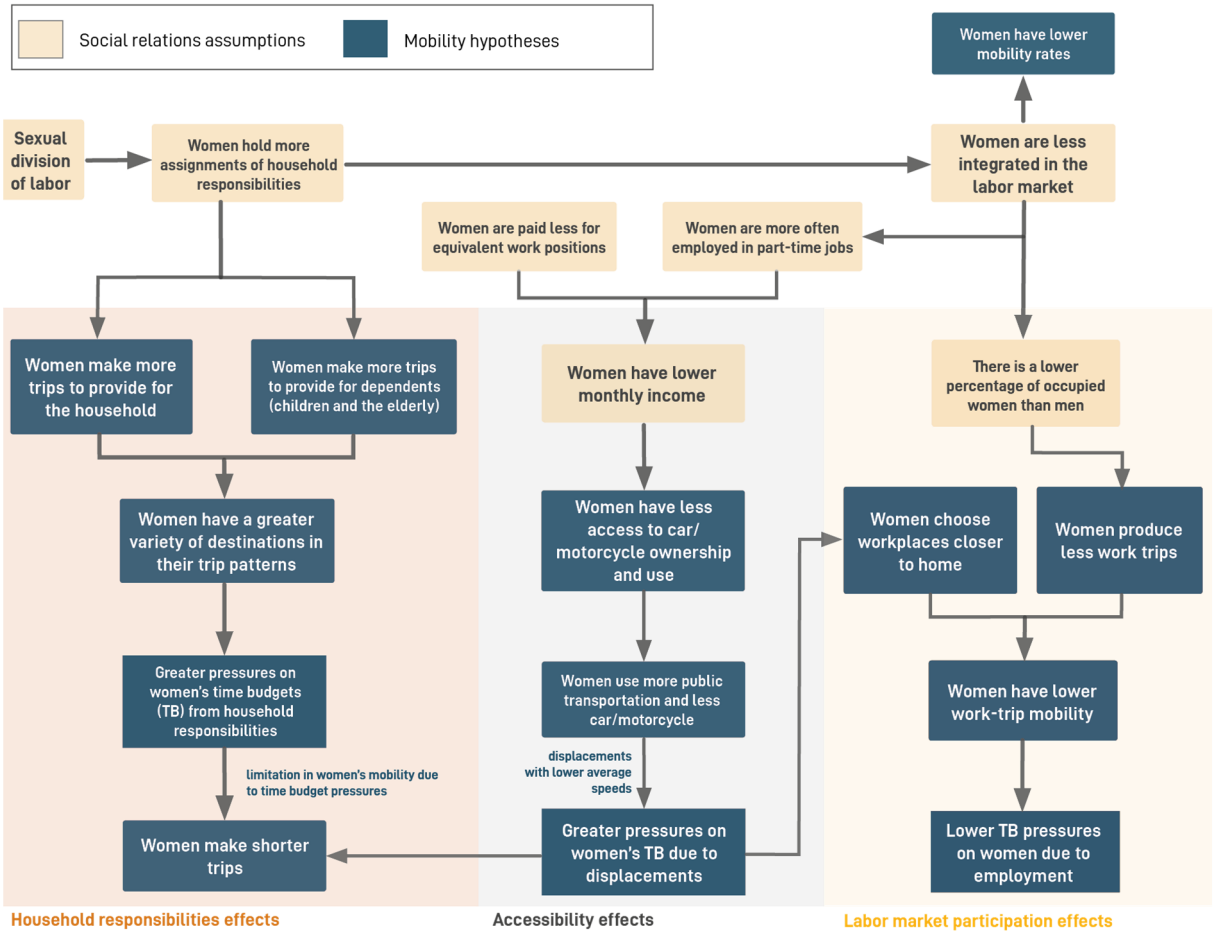

Figure 1. Representation of the problem of inequalities in mobility by gender in large Brazilian cities

Based on the characterization of this issue in large Brazilian cities, Macêdo *et al.* (2020) hypothesized that the sexual division of labor directly influences women's household responsibilities, affecting their professional insertion and impacting their trip patterns. Household responsibilities have effects on mobility by generating multiple travel motives (shopping, carrying dependents, etc.) and consequently multiple destinations. More frequently for men, a greater insertion in the labor market is reflected in a recurring commuting pattern (home-work-home) and in the reduction of the variability of destinations. It is noteworthy that household responsibilities (of which women tend to assume a greater share) compromise the time budget in such a way as to restrict the possibilities of joining the labor market, with a

consequent reduction in individual income, and less access to ownership and use of cars and motorcycles. All these effects generate mobility patterns marked by more chained and shorter trips, and more dependence on public transportation or walking. Building on the initial effort by Macêdo *et al*. (2020), Figure 1 depicts a proposed conceptual representation of the inequality issues in urban mobility levels and patterns between genders in large Brazilian cities.

This representation highlights three dimensions that influence mobility differently by gender: (1) the effects of household responsibilities; (2) the effects of labor market participation (employment); and (3) the effects of accessibility. These three core elements (Figure 2) relate to each other in ways that can induce or restrict mobility, to varying degrees of intensity. For women, the literature review shows that, on average, more trips are produced due to household responsibilities, fewer work trips occur, and lower levels of accessibility are expected (linked to proximity to destinations and modal split).

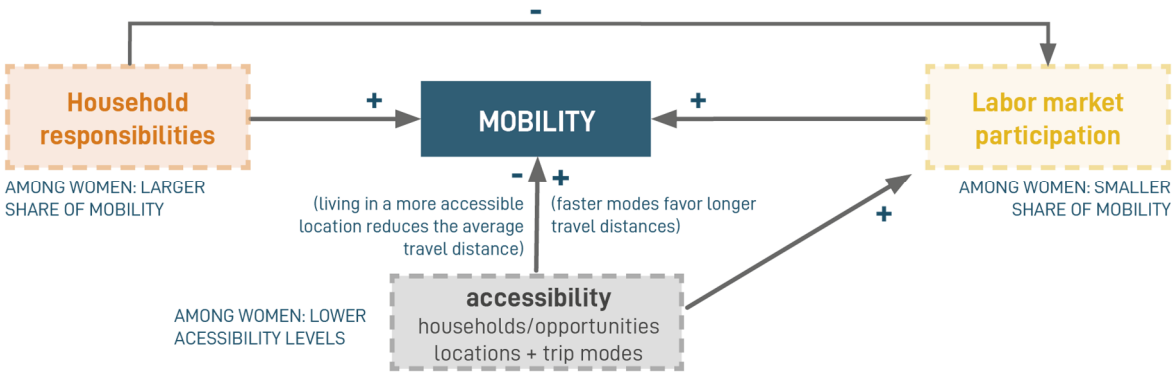

Figure 2. Central elements of the problem of mobility inequalities by gender in Brazil

3. CONSTRUCTION OF THE CAUSALITY HYPOTHESES

In order to diagnose cause-effect relationships in mobility inequalities by gender, based on observational data, the hypotheses of mean differences and correlations inherent in the representation of the problem (Figures 1 and 2) must be translated into causal hypotheses. Causality is assumed to exist between two variables X and Y when, by *varying* the value of X, this leads to a variation in the value of Y, while holding all other variables constant. The *ceteris paribus* condition defines a distinction between correlation and causality, showing that there are causal (causal effects) and non-causal (spurious) sources of correlation (Pearl and Mackenzie, 2018). Cases of spurious association between two variables can occur when they have a common cause, a situation that generates correlation between the variables without implying causal effects.

Pearl (2000) proposed that causality studies should be based on the construction of causal diagrams, defined as a graphic representation of the hypothesized causal process, where the nodes correspond to variables (observed or not) and the directed arrows represent the direction of causality between two variables. Such diagrams translate the hypothesized causalities either by the existence of arrows between two variables or by their absence, which would imply independence. Next, we describe the causality hypotheses concerning the problem of mobility by gender, represented in the proposed causal diagram (Figure 3).

Household responsibilities group together the set of roles and assignments arising from the family structure (composition), that is, the presence of children, teenagers, and the elderly. The increase in these responsibilities translates into an increase in the assignments of those responsible, which leads to higher trip production (Hypothesis H1). The relationship between household responsibilities and individual assignments is complex, as it involves the division of tasks among family members. In this context, the sexual division of labor is a determining factor, manifesting in greater household assignments for women, which leads to a positive causal effect of household responsibilities on trip production, having greater magnitude among women.

In turn, the increase in household responsibilities among family members is interpreted as a limiting (reducing) factor for participating in the labor market (Hypothesis H2). However, given the greater responsibility socially imposed on women for household assignments, it is expected that there is a greater negative effect of household responsibilities among women than among men. Greater participation in the labor market induces (has a positive effect on) commuting (Hypothesis H3); however, its effects on the production of trips are invariant by gender, especially since these are compulsory activities.

Participation in the labor market represents the individual's degree of employability, a factor that induces higher individual incomes, which positively impacts the ownership of private vehicles in the household (Hypothesis H4). However, for the same level of insertion, women obtain lower average monthly incomes (Kergoat, 2003), so that lower effects of market insertion on motor vehicle ownership are expected among women. Increased ownership of cars and motorcycles has a positive impact on the use of these vehicles (Hypothesis H5). However, it is common for the husband to have priority over the use of the family vehicle (Vance and Lovanna, 2007). Therefore, ownership of a motor vehicle is expected to have a less important impact (lower magnitude) on women's mobility.

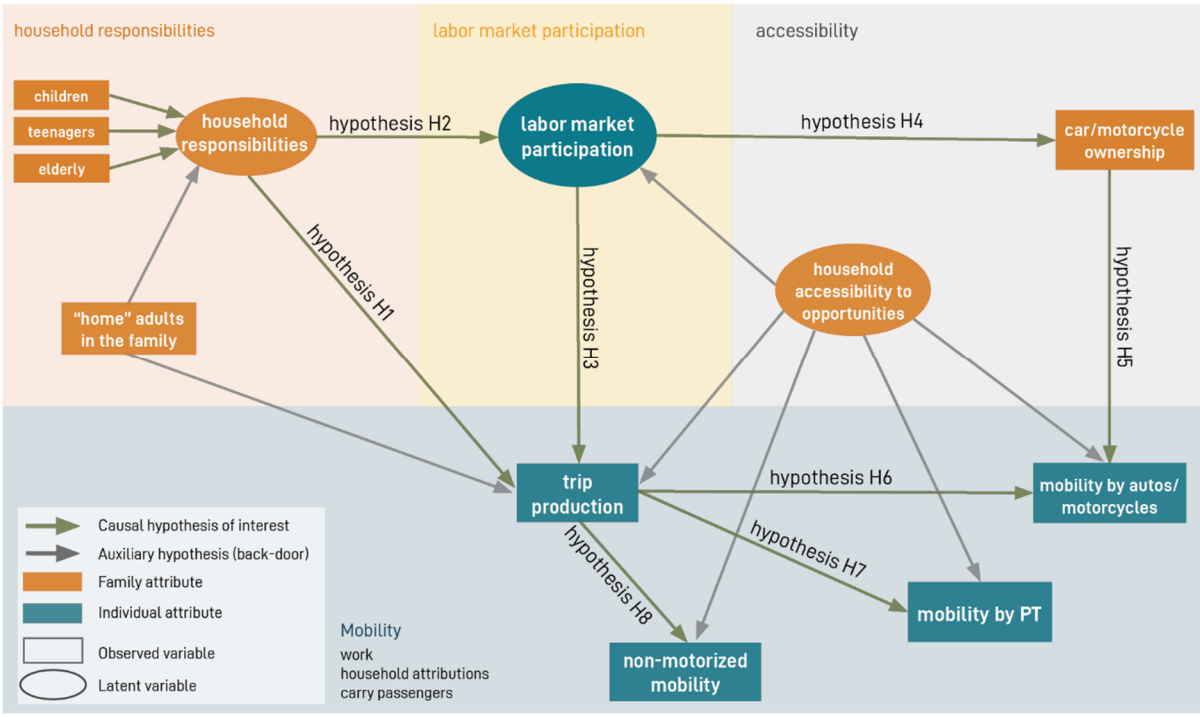

Figure 3. Diagram of causal relationships hypothesized to explain the problem of inequalities in mobility by gender

It is reinforced that the trip production considered here refers only to trips for purposes of work, shopping, and carrying passengers, inherent to the inequality problems represented in Section 2. This trip production manifests itself in mobility by individual motorized modes (Hypothesis H6), collective motorized modes (Hypothesis H7), and non-motorized modes (Hypothesis H8). The relative weight of non-motorized mobility and public transport is hypothesized to be higher among women, as opposed to men who use cars and motorcycles more. Mobility by mode is understood, in this context, as the total distance traveled daily by each mode. Representing mobility by distance rather than by duration reduces the risk of endogeneity by eliminating the influence of congestion levels in the network.

Three control variables were incorporated into the inference of the causal effects of interest (Hypotheses H1 to H8). They were introduced to prevent spurious correlations from being mixed into the causal effects. The presence of "home" adults in the family (non-occupied individuals between the ages of 18 and 65) is seen as the part of the family structure that, despite raising the household responsibilities, plays a co-responsibility role in the household. Household accessibility (proximity to opportunities) is understood as a factor that induces trip production, reduces the total distance traveled, and facilitates participation in the labor market. The third variable is the family socioeconomic status, not shown in Figure 3 to facilitate the understanding of the diagram and to avoid causal cycles, which would greatly increase the complexity of the analyses (Shipley, 2016). A better socioeconomic status raises household responsibilities and the ownership of motor vehicles, in addition to influencing housing locational choices; it is also affected by the participation in the labor market of the family members. To control for its effect, we segmented the sample into different income groups.

4. DATA AND METHODS

This causal inference effort was based on data from household OD surveys, which constitute the most complete source of information about urban mobility patterns, containing detailed information about households, individuals, and their displacements. Recent studies have pointed out that differences in mobility patterns by gender are recurrent features among Brazilian metropolises from different regions (Macêdo *et al.*, 2020). Given the similarities between urban contexts in this issue, the latest household OD survey of the Metropolitan Region of São Paulo (RMSP) was used as representative of this phenomenon for the country's large cities. Its choice is due to (i) tradition and regularity in the elaboration of OD surveys, which increases data reliability; (ii) database containing the georeferenced location of origins and destinations, in addition to detailed information of individuals; and (iii) elevated sample size, allowing to perform segmentations and socioeconomic clippings without compromising the statistical power of the tests (Table 2).

Selection bias is a central concern in inferring causal effects (Shipley, 2016). The sample analysis reveals that, due to the adoption of complex sampling plans, with stratification by socioeconomic criteria (usual in household surveys), the sample composition is not representative of the population in the study area. For example, classes A and B1 represent about 23% of the sample, but correspond to only 13% of the population (ABEP, 2018). An opposite phenomenon (underrepresentation) occurs with the lower-income classes. To avoid bias in the estimates, sample weights were applied to the observations, a procedure adopted in similar studies (Motte-Baumvol and Bonin, 2018).

Table 2 – Description of the sample collected in the RMSP 2017 OD survey

	FAMILY CHARACTERISTICS (n = 32,025)			
Income Class	12% Class A, 11% Class B1, 27% Class B2, 22% Class C1, 17% Class C2, 7% Classes D-E, and 2% no categorization			
	CHARACTERISTICS OF THE INDIVIDUALS (n = 86,318)			
Variable	**Category**	**Female**	**Male**	**Total**
Family Situation	Person in Charge	28%	47%	37%
	Spouse/partner	32%	9%	21%
	Child / Stepchild	29%	35%	32%
	Other relatives	11%	9%	10%
	Resident employee or employee's relative	1%	0%	0%
Age	Under 12 (children)	11%	13%	12%
	Between 12 and 17 (teenagers)	7%	8%	7%
	Between 18 and 40 (adults)	32%	34%	33%
	Between 40 and 65 (adults)	35%	32%	34%
	Between 65 and 80 (elderly)	11%	10%	11%
	80 or more (elderly)	4%	2%	3%
	TRIP CHARACTERISTICS (n = 157,992)			
Trip purpose	Work	39%	50%	44%
	School/Education	21%	22%	21%
	Shopping	6%	4%	5%
	Carrying passenger	16%	11%	13%
	Other reasons	18%	14%	16%
Main trip mode	On foot	32%	29%	31%
	Bicycle	0%	1%	1%
	Public Transport	36%	29%	32%
	Individual Motorized	32%	41%	36%

4.1. Population of interest

Since the study is focused on explaining travel behavior between gender groups, the observational unit adopted is the individual (as opposed to the family or household). The delimitation of the population of interest involves two basic criteria: a spatial criterion, related to the scope of the study area, and a socioeconomic delimitation of the individuals. In the first place, considering the focus given to the diagnosis of a problem common to large Brazilian cities, it was decided to use sample records only from the municipality of São Paulo, not considering, therefore, the other municipalities of its Metropolitan Region, which corresponds to retaining about 2/3 of the records.

As for the second criterion, the study context that motivated the construction of the causal diagram presented in Figure 3 refers to individuals who are sensitive to the sexual division of labor and who make travel decisions. In this sense, it is desired to incorporate adult individuals who have household responsibilities and are of working age (corresponding to the family status of "Person in Charge" or "Spouse/Partner"). Children, teenagers, and people with motor limitations do not make up the sample analyzed. Thus, only individuals between the ages of 18 and 80 were retained in the sample. The upper age limit aims to filter individuals with mobility limitations, since the survey does not explicitly collect this information.

4.2. Structural Equation Modeling (SEM)

Several statistical models are capable of being used to measure causality through the analysis of their coefficients, which have partial effect interpretation, or *ceteris paribus* (Wooldridge, 2013). In this research, SEM modeling was adopted for the following aspects: (i) it allows a

multivariate regression approach, useful for assessing causal hypotheses linked by direct and indirect effects; (ii) it enables incorporating unobservable (latent) variables, (e.g., "household responsibilities"); (iii) it allows relaxing classical regression assumptions regarding residual error distributions and multicollinearity (Hoyle, 2012; Kline, 2011).

The causal diagram shown in Figure 3 is converted into a series of structural equations, in which each variable is *explained* only by its direct causes, a property called the Markov condition (Pearl, 2000). When converting causal relationships into structural equations, the arrows become equal signs, so that the variable to the left of the sign is *explained*, while the variables to the right of the sign are *explanatory*. Each endogenous variable gives rise to a structural equation, some of which are reproduced below:

$$needsFamily = f(children, teenagers, elderly, adultsHome) \quad (1)$$

$$productionTravel = f(needsFamily, market\ insertion, adultsHome, accessibility) \quad (2)$$

$$mobilityAuto = f(productionTrips, ownershipVehicles, accessibility) \quad (3)$$

Given its complexity, causal inference efforts do not aim to incorporate all explanatory factors of the variables of interest, but only to incorporate the causal hypotheses of interest and possible sources of confounding, eliminating the occurrence of endogeneity. A *residual error* component was incorporated into all endogenous variables in the model, which gathers all the explanatory factors of the variables that were not systematized.

The existence of unobserved (latent) variables in the causal model requires additional models, called measurement models. Latent variables can be classified into two main types (Grace and Bollen, 2008): formative or reflective. Formative latent variables are constructs that, although unobserved, have well-determined causes, so that it is possible to *explain* the latent variable by observing its causes (formative indicators). This approach requires that all the main causes of the latent variable be systematized, which is a complex challenge (Bollen and Bauldry, 2011). Reflective latent variables, on the other hand, are *represented* by observing their effects (reflective indicators), that is, variables are observed that have the latent variable as a common cause. To model reflective latent variables, techniques from the social sciences are used, known as Confirmatory Factor Analysis (Brown, 2006).

Measurement models were formulated for the latent variables: Household Responsibilities; Labor Market Participation; and Household Accessibility. In all three cases, we chose to specify reflective latent variables, in which the indicators correspond to the consequences of the latent variables. It is indicated to construct latent variables with at least two indicators (Shipley, 2016), allowing to separate measurement errors of each indicator and perform statistical tests on the represented constructs. Table 3 summarizes the indicators chosen to represent the three latent variables.

Table 3 – Specification of (reflective) measurement models

Latent Variable	Indicators
Household responsibilities	Carry passenger trips, made by the family
	Educational trips, produced by the family
	Trips for other reasons, produced by the family
	Different destinations reached by the family
Labor Market Participation	Daily hours worked (hours)
	Number of Jobs
	Individual income status (has income / has no income)
Household Accessibility	Cumulative opportunities to jobs (considering a time range of 60 minutes, by public transport)
	Weighted average distance to institutions (opportunities)

The causal hypotheses presented in Figure 3 imply that heterogeneous causal processes occur between individuals of both genders. In this sense, despite having the same causal diagram for both gender groups, it is understood that there are distinctions in the magnitudes of the relative effects (see Section 3). Thus, a simultaneous SEM estimation was performed for several groups (multigroup SEM), allowing later comparisons of the estimates. Four groups were considered: Low-Income Female (FbR); High/Middle-Income Female ($FamR$); Low-Income Male (MbR); and High/Middle-Income Male ($MamR$). The low-income group includes socioeconomic classes C/D/E, while the high/middle-income group includes classes A/B (ABEP, 2018).

In SEM models, the choice of the type of estimation has great relevance, since each estimator has different assumptions about the distribution of the residual errors of the endogenous variables. Considering the probable non-normality of the variables and the adoption of categorical indicators, the *Weighted Least Squares* estimator was used, which relaxes distributional assumptions existing in the maximum likelihood estimator (Brown, 2006). As for goodness of fit measures, despite their use being criticized in causal inference (Shipley, 2016), the GFI and CFI were adopted, which have values close to 1 in well-fitting models (Hoyle, 2012).

5. STRUCTURAL EQUATION MODELING RESULTS

The SEM model of mobility by gender/income was estimated using the *lavaan* package in R language, and the *lavaan.survey* extension, which is necessary to perform estimates considering the sample expansion factors of the observations. In this process, the measurement and structural models are estimated jointly, in an effort to minimize the differences between the observed (sample) and modeled covariance matrix, which arises from the estimates of the structural coefficients. The results, shown in Figure 4, contain the standardized coefficient estimates (adjusted for null mean and unit variance) for the four established groups. The models proved adequate in explaining the associative patterns, which is manifested in the satisfactory adherence conditions (GFI: 0.94; CFI: 0.86). The estimates, all significant with α=1%, support the hypothesis of distinct causal processes explaining travel decisions across gender groups, as the magnitude of causal effects depends on the stratum considered.

For conciseness, we chose not to represent the measurement models, which are briefly discussed below. The indirect measurement of "household responsibilities" through the derived trip production needs was quite satisfactory, allowing to overcome a major limitation of studies on gender and mobility, which is the estimation of household assignments. The model for measuring "labor market participation" showed different results for men and women and a higher correlation between the number of jobs and working hours among women, potentially explaining the greater occurrence of part-time jobs in this group.

Representing “Accessibility” as a latent variable proved to be an adequate method, given its complex and multidimensional nature (Geurs and Van Wee, 2004). Thus, measuring accessibility with the cumulative job opportunities indicator allowed to incorporate the locational (i.e. land use) and infrastructural (i.e. transport) components of accessibility; the weighted distance to opportunities indicator allowed to expand the representation of accessibility by considering the different categories of opportunities (not only job opportunities). As expected, the two indicators were negatively correlated, since higher accessibility levels occur with more cumulative opportunities and smaller distances to opportunities.

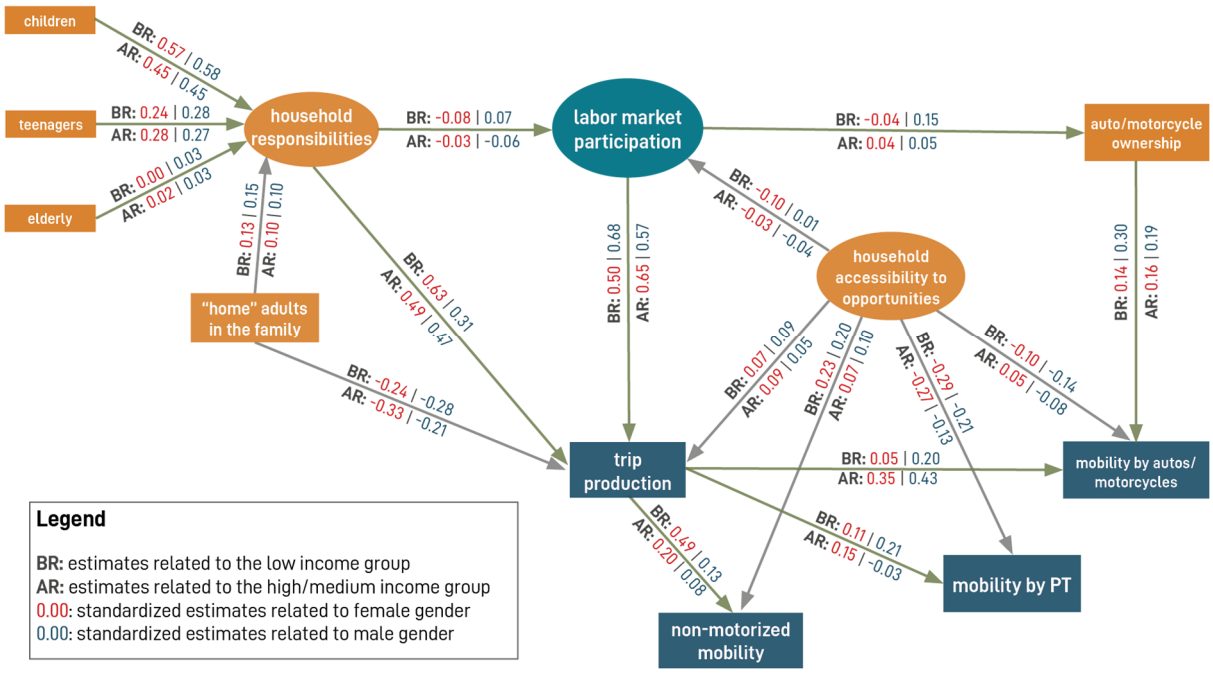

Figure 4. SEM model estimation results by gender/income groups

5.1. Effects of household responsibilities

The direct effect of household responsibilities on trip production is always higher among women at a significance level of 1%, indicating that women's household roles are, on average, higher than men's, manifesting in higher trip production. Note that the gender differences vary across income strata: while the causal effect for FbR (0.63) is double the effect for MbR (0.31), we observe, on average, a greater balance between $FamR$ (0.49) and $MamR$ (0.47). This is a strong indication that the gender issue is heterogeneous across income classes.

The household responsibilities are mostly explained by the presence of children and teenagers. The total effect of the presence of children on the trip production is estimated considering the sum of the indirect impact transmitted through household responsibilities and also through labor market participation; being, in the low-income classes, equal to 0.34 (i.e. $0.57\ x\ 0.63 + 0.57\ x - 0.08\ x\ 0.50$) among women and only 0.21 among men. The almost null effect of the presence of elderly people (over 65 years old) is attributed to the heterogeneity of the mobility conditions of this group, remembering also that the household responsibilities may be derived from elderly people who do not live at home, not considered in this study. The control variable "home adults" reflects the importance of co-responsibility in household assignments, since the negative effect of this variable on trip production indicates the reduction of the average workload by sharing household assignments among family members.

5.2. Effects of labor market participation

The hypothesis that household responsibilities act as limiting factors for labor market participation was corroborated. In the FbR classes, there is a negative causal effect of household responsibilities on labor market participation (-0.08), while for MbR this effect is positive (0.07). This result seems to reflect two important elements of this social issue: on the one hand, the greater degree of household responsibilities among women limits their insertion in the

labor market; and on the other, the greater complexity of the family structure leads to a greater need to provide for the home.

Still in this context, it is evident that the relative importance between labor market participation and household responsibilities with regard to trip production varies among groups. For FbR, there is a greater relative weight of family needs (0.63) compared to labor market participation (0.50), a situation that is reversed for MbR. In higher-income classes, however, for both genders there is a greater relative weight of labor market participation in trip production, which is another indication of smaller average differences between genders in higher income classes.

Labor market participation has a positive causal effect on motor vehicle ownership, except for FbR (-0.04). The models show that the effect of a more active professional life is much higher for MbR (0.15). This translates to lower average earnings among women for similar levels of market insertion. In higher-income classes the effects are almost identical between genders, indicating a situation of lower inequalities in wage levels.

5.3. Effects of accessibility

Car/motorcycle ownership has a positive effect on their use, as measured by total distance traveled by these modes. The effect of car/motorcycle ownership for MbR (0.30) is double that observed for FbR (0.14). This means that, all other factors held constant, the ownership of these vehicles has a greater impact on men, which reinforces the idea that men have priority over their use, explaining, in part, their greater motorization. As for the causal effects for $FamR$ and $MamR$, we observe a greater balance in this situation. This result confirms that women have limited accessibility due to the lower ownership and use of cars and motorcycles, with greater pressure on their time budget.

The accessibility variable, which represents the spatial proximity to opportunities, proved to be an important control variable for mobility variables. Despite having little inductive effect in trip production (restricted, in this study, to trip purposes work, shopping and carrying passengers), accessibility acts as a limiting factor of mobility by public transport, since, due to limitations in the time budget of men and women, the adoption of this mode restricts the average distances traveled, as it is slower than individual motorized modes. The opposite effect is observed in non-motorized mobility: people living close to opportunities are more likely to move by walking and cycling.

5.4. Mobility patterns by mode

The results reinforce the hypotheses raised about the different mobility patterns by mode between gender groups. For low-income women, non-motorized mobility has a much higher relative effect (0.49) than the effects of the other modes, while among men there is considerable participation in the use of public transportation (0.21) and individual motorized modes (0.43). In higher-income classes, both men and women travel more by individual motorized modes, although there is still a higher relative weight of these modes among men.

6. CONCLUSIONS AND RECOMMENDATIONS

Despite the existence of extensive literature addressing the problem of gender in urban mobility, the explicit investigation of causal hypotheses of this problem with statistical tools is limited. In this sense, this work sought to overcome these gaps, bringing not only the theoretical

framework of Pearl's causal inference (2000), but also the use of multivariate statistical models, which allowed the simultaneous investigation of several causal hypotheses. The SEM modeling proved useful in the study of causality, especially with the adoption of the multigroup approach, which allowed us to confirm the existence of distinct causal processes both between genders and among income strata, as evidenced by the different effect estimates. The *a priori* causal diagram, moreover, proved suitable to confirm the hypotheses formulated based on the literature review. In this effort, associative relations were translated into explanations, evidencing a complex causal process, composed of direct and indirect effects. The undergone diagnostic effort showed *why* the sexual division of labor plays a determining role in the patterns of mobility between genders, an explanation that involves three key elements: household responsibilities, labor market participation, and household accessibility to opportunities.

The contributions of this work have important implications for the urban planning process and the proposition of transportation policies. The current paradigm of accessibility planning, which is usually based on locational accessibility measures relative to the household, hides significant gaps in accessibility by gender within households, resulting from the greater ownership and use of individual motorized modes among men. In this sense, it seems necessary to consider, in addition to household-based measures, accessibility indicators based on the individual, which incorporate the different opportunities offered by gender and the different modal alternatives available.

It follows from the obtained results that the development of public policies aimed at increasing the attractiveness of active modes and public transport seems to have a differential positive impact on the female gender, in particular for the low-income population. The emerging micromobility alternatives may play an important role in this context, given the shorter average commuting distances, and the possibility of integration with public transportation. It is necessary to recognize, however, that reducing the impedance of women's travel encompasses another equally complex issue of road and public safety.

The incorporation of income in the explanation of mobility patterns, which traditionally sought to translate the impact of socioeconomic status in inducing needs and desires for activities, gains a new perspective on the gender problem. It has been shown that income brings heterogeneity in travel decisions, and it is not only necessary to control for the effect of income but also to incorporate this heterogeneity through the segmentation of these groups. Gender differences are more sensitive in low-income households, which are also the share of the population with greater difficulty in accessing opportunities in Brazil's large cities. In higher-income classes, not only gender differences are attenuated, but the impact of mode on accessibility tends to be smaller, given the greater proximity to opportunities, in general.

Despite the contributions achieved in this work, several research gaps can still be identified in the gender issue. We still need to understand how the role of the sexual division of labor in the issue of gender inequalities has evolved over time, especially in the first two decades of the 21st century. Moreover, we need to understand the moderating role of family income in gender relations, treated here only as two large and heterogeneous income groups. Finally, we point out the importance of conducting further analyses to understand other factors that influence mobility by gender, such as public violence, which can be significant on mobility by non-motorized modes and by public transportation.

ACKNOWLEDGEMENTS

This work was partially funded by the Brazilian National Council for Scientific and Technological Development (CNPq), as well as by the Coordenacao de Aperfeicoamento de Pessoal de Nivel Superior (CAPES).

REFERENCES

ABEP. (2018) *Alterações na aplicação do Critério Brasil, válidas a partir de 16/04/2018*. São Paulo: ABEP. Available at: < https://www.abep.org/criterioBr/01_cceb_2018.pdf> (accessed: 21/03/2022).

Bollen, K. A. and Bauldry, S. (2011) Three Cs in Measurement Models: Causal Indicators, Composite Indicators, and Covariates. *Psychological Methods*, *16*(3), 265–284. DOI: 10.1037/a0024448

Brown, T. A. (2006) *Confirmatory Factor Analysis for Applied Research*. *Methodology in the Social Sciences*. New York: The Guilford Press.

CIVITAS. (2014) *Gender equality and mobility: Mind the gap!*. European Union, 1–48. Available at: <https://civitas.eu/sites/default/files/civ_pol-an2_m_web.pdf> (accessed: 21/03/2022).

Crane, R. (2007) Is there a quiet revolution in women's travel? Revisiting the gender gap in commuting. *Journal of the American Planning Association*, *73*(3), 298–316. DOI: 10.1080/01944360708977979.

Duchène, C. (2011) *Discussion Paper No. 2011-11: Gender and Transport*. International Transport Forum. Available at: <https://www.itf-oecd.org/sites/default/files/docs/dp201111.pdf> (accessed: 21/03/2022).

Fanning Madden, J. (1981) Why Women Work Closer to Home. *Urban Studies*, *18*(2), 181–94. DOI: 10.1080/00420988120080341

Geurs, K.T. and B. Van Wee (2004) Accessibility Evaluation of Land-Use and Transport Strategies: Review and Research Directions. *Journal of Transport Geography,* 12, 127-140. DOI: 10.1016/j.jtrangeo.2003.10.005

Gimenez-Nadal, J. I. and J. A. Molina (2016) Commuting time and household responsibilities: Evidence using propensity score matching. *Journal of Regional Science*, *56*(2), 332–359. DOI: 10.1111/jors.12243

Gonzalez, K. D.; A. L. Machado; B. B. Alves; V. I. Raffo; S. G. Gomez and I. Portabales (2020) *Why does she move?: A study of women's mobility in Latin American cities*. Washington: World Bank. DOI: 10.1596/33466

Grace, J. B. and K. A. Bollen (2008) Representing general theoretical concepts in structural equation models: The role of composite variables. *Environmental and Ecological Statistics*, *15*(2), 191–213. DOI: 10.1007/s10651-007-0047-7

Hanson, S. (2010) Gender and mobility: New approaches for informing sustainability. *Gender, Place and Culture*, *17*(1), 5–23. DOI: 10.1080/09663690903498225

Hanson, S. and I. Johnston (1985) Gender differences in work-trip length: Explanations and implications. *Urban Geography*, *6*(3), 193–219. DOI: 10.2747/0272-3638.6.3.193

Hoyle, R. H. (2012) *Handbook of Structural Equation Modeling*. New York: The Guilford Press.

Kergoat, D. (2003) Divisão sexual do trabalho e relações sociais de sexo. In Emílio, M.; M. Teixeira e M. Nobre (eds.) . *Trabalho e cidadania ativa para as mulheres: Desafios para as Políticas Públicas*. São Paulo: Coordenadoria Especial da Mulher, pp. 55–63.

Kline, R. (2011) *Principles and Practice of Structural Equation Modeling*. Third Edition. New York: The Guilford Press.

Lecompte, M. C. and B. S. Juan Pablo (2017) Transport systems and their impact on gender equity. *Transportation Research Procedia*, *25*, 4245–4257. DOI: 10.1016/j.trpro.2017.05.230

Macêdo, B.; D. G. L. Pinto; M. F. Siqueira; A. S. Lopes and C. F. G. Loureiro (2020) Caracterização das diferenças do padrãode mobilidade de mulheres e homens em grandes cidades brasileiras. Transportes, 28(4), p. 89–102. DOI: 10.14295/transportes.v28i4.2410.

Miralles-Guasch, C.; M. M. Melo and O. Marquet (2016) A gender analysis of everyday mobility in urban and rural territories: from challenges to sustainability. *Gender, Place and Culture*, *23*(3), 398–417. DOI: 10.1080/0966369X.2015.1013448

Motte-Baumvol, B. and O. Bonin (2018) The spatial dimensions of immobility in France. *Transportation*, *45*(5),1231-1247. DOI: 10.1007/s11116-017-9763-5

Pearl, J. (2000) *Causality: Models, reasoning, and inference*. First Edition. New York: Cambridge University Press. DOI: 10.1017/CBO9780511803161

Pearl, J. and D. Mackenzie (2018). *The Book of Why: The New Science of Cause and Effect*. New York: Basic Books, Inc. DOI: 10.1080/01621459.2020.1721245

Peters, D. (2001) Gender and transport in less developed countries : A background paper in preparation for CSD-9. *Gender Perspectives for Earth Summit 2002: Energy, Transport, Information for Decision Making*, 1–30. Available at: <https://api.semanticscholar.org/CorpusID:150372464> (accessed: 21/03/2022).

Pinheiro, L.; N. O. Fontoura; A. C. Querino; A. Bonetti and W. Rosa (2009) *Retrato das desigualdades de gênero e raça.* Third Edition. Brasília: Instituto de Pesquisa Econômica Aplicada.

Prashker, J.; Y. Shiftan and P. Hershkovitch-Sarusi (2008) Residential choice location, gender and the commute trip to work in Tel Aviv. *Journal of Transport Geography*, *16*, 332–341. DOI: 10.1016/j.jtrangeo.2008.02.001

Root, A. and L. Schinder (1999) Women, motorization and the environment. *Transportation Research Part D: Transport and Environment*, *4*(5), 353–355. DOI: 10.1016/S1361-9209(99)00012-7

Rosenbloom, S. (2006) Understanding Women's and Men's Travel Patterns: The Research Challenge. *Conference on Research on Women's Issues in Transportation*, *1*(35), 7–28. DOI: 10.17226/23274

Rosenbloom, S. and M. Plessis-Fraissard (2010) Women's Travel in Developed and Developing Countries. *Transportation Research Board Conference Proceedings 46*. DOI: 10.17226/22901

Scheiner, J. and C. Holz-Rau (2017) Women's complex daily lives: a gendered look at trip chaining and activity pattern entropy in Germany. *Transportation*, *44*(1), 117–138. DOI: 10.1007/s11116-015-9627-9

Shipley, B. (2016) *Cause and Correlation in Biology.* Second Edition. Cambridge: Cambridge University Press.

Srinivasan, S. and P. Rogers (2005) Travel behavior of low-income residents: Studying two contrasting locations in the city of Chennai, India. *Journal of Transport Geography*, *13*(3), 265–274. DOI: 10.1016/j.jtrangeo.2004.07.008

Svab, H. (2016) *Evolução dos padrões de deslocamento na Região Metropolitana de São Paulo: A necessidade de uma análise de gênero*. Master's Thesis. Escola Politecnica, Universidade de São Paulo. São Paulo. DOI: 10.11606/D.3.2016.tde-30092016-142308

Vance, C. and R. Lovanna (2007) Gender and the automobile: Analysis of nonwork service trips. *Transportation Research Record*, (2013), 54–61. DOI: 10.3141/2013-08

Venter, C.; V. Vokolkova and J. Michalek, (2007) Gender, residential location, and household travel: Empirical findings from low-income urban settlements in Durban, South Africa. *Transport Reviews*, *27*(6), 653–677. DOI: 10.1080/01441640701450627

Wooldridge, J. M. (2013) *Introductory econometrics : a modern approach.* 7th Edition. Boston: Cengage Learning.