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IMPACT OF PASSENGER TRANSPORTATION MODES, TRAVEL CHOICES, AND URBAN GEOGRAPHY ON CO_2 EMISSIONS

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1. INTRODUCTION AND MOTIVATION

Policies that encourage reduced vehicle-miles traveled and the use of more efficient transportation modes in urbanized areas are typically considered as means to reduce greenhouse gas (GHG) emissions. However, no definitive quantifications are yet available regarding the potential benefits that could be derived from such policies in terms of potential reductions in greenhouse gas (GHG) emissions. In this study, quantified effects are determined and their policy implications are discussed.

The infrastructure supporting urban passenger transportation encompasses complementary and competing modes of travel, including private vehicle, urban street bus transit, bus rapid transit, light rail, and heavy rail. (Walking and biking, which are viable on a large scale in some urbanized areas, are not considered in this study given the focus on US urbanized areas where such modes are currently limited.) The different modes involve multiple characteristics in terms of cost, service, energy consumption, and environmental impacts. Some discretionary travelers could choose among several of the modes when making many of their trips, whereas other captive travelers have limited options. Moreover, the urban form and the corresponding origin-destination flow patterns have a direct bearing on the modes offered in terms of the spatial and temporal nature of the various services and, consequently, on the choices made by travelers. Given the varying supply and demand characteristics of the multiple modes across urbanized areas, passenger transportation related energy consumption and GHG emissions per traveler are expected to be associated with these characteristics. For example, due to the efficient nature of public transportation and the greater flexibility this mode offers in relying on different sources of energy, it is expected that, in general, an increased use of this mode has potential advantages in reducing GHG emissions. Similarly, high private vehicle occupancy is expected to mitigate the negative effects of the single-occupancy vehicle mode. In addition, reduced overall travel irrespective of the modes used is expected to lead to a reduction in GHG emissions.

Travel choices are made at the individual level, while transportation and land-use policies are made at the government level. Clearly, policies have the potential to influence travel choices, while at the same time, the actual choices made under new policies directly determine their impact. Therefore, in support of evidence-based policy-making, it is important to establish a good understanding of the effects various passenger travel related variables have on GHG emissions and the magnitudes of those effects in urbanized areas. Moreover, it is equally important to take into account the effect of policies aimed at reducing GHG emissions in doing so.

Several studies found clear relationships linking urban form and transportation related variables to GHG emissions (Newman and Kenworthy, 1989; Lomax et al., 1994; Holtzclaw et al., 2002; Bento et al., 2005; Ewing et al., 2007; Glaesar and Kahn, 2008; Hankey and Marshall, 2010; Parshall et al., 2010; Barla et al., 2011). In addition, some studies have investigated the relationship between transportation and GHG emissions and opportunities to mitigate such emissions (Cambridge Systematics, Inc , 2009; Kockelman et al., 2009; Lindsey et al., 2010; Maghelal, 2011; Southworth and Sonnenberg, 2011). However, these studies do not directly model and quantify the effect of high-occupancy vehicle (HOV) use – whether transit or high-occupancy private automobiles – on GHG emissions. Moreover, in modeling the effects of interest, these studies do not recognize the effects of present policies aimed at reducing GHG and the dual relationships such policies could have with GHG emissions. On the one hand, such policies may be effective in reducing GHG emissions. On the other hand, such policies are more likely to be adopted in urbanized area in response to relatively higher levels of GHG emissions in these areas.

In addition to CO_2, GHG includes Hydrofluorocarbons (HFCs) and nitrous oxide (N_2O), among others. In this study, only CO_2 emissions are examined since these emissions constitute 93.4% of the GHG produced in the transportation sector (Energy Information Administration, 2008). Moreover, the CO_2 emissions focused on are those resulting from passenger travel and the impacts of travelers' choices within the context of available infrastructure and existing urban form. More specifically, various urban travel choices, travel characteristics, and travel and land-use related policies are related to annual CO_2 emissions produced as a direct result of passenger transportation. Therefore, unlike some other studies, freight transportation is not considered in this study. Furthermore, CO_2 emissions resulting from the construction of transportation infrastructure and the manufacturing of passenger vehicles (private and public) are outside the scope of this study. That is, the focus is on the marginal impacts related to the passenger travel use-phase rather than the total life-cycle impacts. The rationale motivating the marginal nature of the scope of this study is to quantify relative changes in CO_2 emissions resulting from policies and regulations that might produce changes in existing conditions, a common scenario that policy-makers in urbanized areas face.

In previous efforts conducted by this team (Mishalani and Goel, 2011; Mishalani et. al., 2014; Mishalani and Goel, 2015), the following was achieved. First, a comprehensive dataset is integrated by including data from multiple sources on the largest 146 urbanized areas in the US in a manner that achieves consistency across the variables. Second, potentially critical variables to the understanding of passenger travel related CO_2 emissions including HOV use and a proxy variable indicative of the presence of policies aimed at reducing GHG levels and travelers' attitudes behaviors towards environmental concerns are incorporated in the dataset. Third, an aggregate model of urban passenger travel related CO_2 emissions in US urbanized areas that includes a rich set of explanatory variables is developed whereby the roles of policies aimed at improving the environment or could enhance the attitudes of travelers towards making environmentally favorable choices is captured through the use of a proxy variable. Fourth, the possible presence of selectivity bias resulting from the hypothesized effects of such environment enhancing policies is accounted for in the model estimation and, as a result, an improved quantification of the explanatory effects of transportation demand and supply, population density, and policy variables is arrived at.

The contributions of this study are twofold. First, the impacts of changes in the various travel related, population density, and policy variables on CO_2 emissions are quantified. Second, the implications of these quantifications on policy-making are identified and discussed. In Section 2 of this report, the statistical model previously arrived at is summarized. In Section 3 the analysis leading to the quantification of impacts is presented along with the results. In Section 4 the policy implications are discussed. In the final section directions for future research are identified.

2. SUMMARY OF PREVIOUSLY DEVELOPED STATISTICAL MODEL

The data considered relates to the years ranging from 2000 to 2003 for the largest 146 urbanized areas in the US. The dependent variable of interest is the CO_2 emissions per capita in urbanized areas produced as a direct result of passenger travel using all modes. The units used are metric tons of CO_2 per year and the determined CO_2 emissions are normalized by the total population of the urbanized area. The variables considered either as explanatory variables or used in some form for the model estimation include transit share (the ratio of transit passenger-miles to the total passenger-miles traveled), transit service utilization (transit passenger miles traveled per transit space miles provided), average private vehicle occupancy (number of travelers per private vehicle), freeway lane-miles per capita, criteria auto emissions (CO and NO_x) (metric tons per square mile), auto emissions inspection (whether in place for an urbanized area or not), median income (US dollars), average travel time (minutes), population density (persons per square mile), and variation in population density (coefficient of variation of population density across zip code regions within an urbanized area).

The interrelationships between possible explanatory variables that have relatively high correlation coefficients with CO_2 per capita in absolute value terms were explored via bivariate scatter plots. All of the examined variables exhibit relationships with CO_2 per capita that are consistent with the *a priori* expectations discussed above. Because population density appears to have a non-linear, inverse relationship with CO_2 per capita, density was transformed to 1/density. A similar relationship for cities around the world has also been found (Karathodorou, 2010). A comprehensive statistical modeling was conducted, the details of which are presented in Mishalani et al. (2014) and Mishalani and Goel (2015). For convenience, the final estimation results are shown in Table A.1 of the Appendix.

The model is segmented by the automobile inspection variable. That is, the same specification is estimated separately for urbanized areas with automobile inspection programs and for those without such programs. The variables included in the final model of Table A.1 are those that exhibit coefficients that are statistically significant at at least the 10% significance level in at least one of the two sets of estimates. They include transit share, freeway lane miles per capita, average travel time, average private vehicle occupancy, 1/density, and the term used to correct for selectivity bias (discussed in more detail subsequently). The coefficients of all the explanatory variables except for 1/density are found to be significantly different from one another for urbanized areas with inspection compared to those without inspection (Mishalani et al. 2014; Mishalani and Goel, 2015) validating the importance of this proxy variable. Detailed interpretation of the estimation results and discussion of variables not found to have statistically significant coefficients are presented in Mishalani et al. (2014) and Mishalani and Goel (2015).

Of note in estimating this model is the correction of selectively bias stemming from the dual relationships between CO_2 per capita and the proxy automobile inspection variable. These relationships and the correction of the resulting selectively bias are discussed at length in Mishalani et al. (2014) and Mishalani and Goel (2015). Briefly, the selectivity bias correction is achieved by applying a methodology proposed in Mannering (1987) – see also Washington et al. (2003) – where two models are estimated whereby the results of the first are used in estimating the second. The first model describes the decision to institute an automobile inspection program and the second is the model of interest, where CO_2 emissions per capita is regressed against several explanatory variables and the additional selectivity bias correction variable determined from the results of the first model. In the first model, the decision is specified to be a function of CO per unit area and NO_x per unit area because CO and NO_x criteria vehicle emissions are two primary pollutants that inspection and maintenance programs test for (Rilett, 2002). The reason behind normalizing these criteria emissions by area for the purpose of the first model is discussed in Mishalani et al. (2014) and Mishalani and Goel (2015).

3. IMPACTS QUANTIFICATIONS AND INTERPRETATIONS

To investigate the magnitudes of the possible impacts on CO_2 emissions that changes in certain variables might have, the estimated model is used to quantify such impacts for fifteen specially selected urbanized areas. The urbanized areas reflecting the four smallest, the middle four, and the four largest CO_2 emissions per capita are chosen for further analysis. In addition, the urbanized areas that contain New York City and Los Angeles, both of which have automobile inspection programs, are included in the analysis because they have the highest populations. Finally, Miami, FL is also included because it has a noticeably large population amongst the urbanized areas without an emissions inspection program in place. Among the selected fifteen urbanized areas, seven have emissions inspection programs and eight do not.

The magnitude of the change in CO_2 emissions for each of these urbanized areas when each of the explanatory variables is increased by 10%, all else being equal, are shown in Table 1. In the cases where a variable's coefficient is not statistically significant at the 10% significance level in either the estimation results where automobile inspection programs are present or those where such inspection programs are not present, the corresponding changes in CO_2 emissions are not reported. Since the model specification is linear with respect to transit share, freeway lane-miles per capita, average travel time, and average private vehicle occupancy, if these variables were reduced by 10%, the resulting changes in CO_2 emissions would be negative but of the same numerical value in absolute terms. While the results reported in Table 1 are specific to the 15 urbanized areas reported on, the findings discussed subsequently based on these urbanized areas are in general representative of all the urbanized areas considered in estimating the model.

As can be seen from the results of Table 1, appreciably different changes in CO_2 emissions are predicted in the presence and absence of the proxy automobile emissions inspection – not surprisingly given the differences in the estimated coefficients. In the absence of inspection, average private vehicle occupancy has by far the largest impact on CO_2 emissions (this result applies to all 76 urbanized areas without inspection programs), whereby an increase in private vehicle occupancy leads to an appreciable reduction in CO_2 emissions – up to 1.8M metric tons per year for Miami, FL, when private vehicle occupancy increases by 10% from 1.199 to 1.319 – all else equal. However, the role of this variable is not significant in the presence of inspection. This result is not surprising since in the absence of policies aimed at reducing GHG emissions or in the case of less environmentally favorable travel attitudes and behaviors, scenarios argued to likely be associated with the absence of inspection, there are more opportunities for reducing GHG emissions by increasing vehicle occupancy.

In the presence of inspection, the variable that has the largest impact (for five of the seven urbanized areas whose results are shown in Table 1 and for 50 of the 70 with inspection programs) is freeway lane-miles per capita, whereby an increase in the supply of freeway lane-miles per capita leads to an appreciable increase in CO_2 emissions – up to 0.8M metric tons per year for New York-Newark, NY-NJ-CT, when freeway lane-miles per capita increases by 10%

from 0.000405 to 0.000445 – all else equal. However, the role of this variable is not as appreciable in the absence of inspection. One possible explanation of this difference could be that in the presence of environmentally favorable travel attitudes and behaviors, argued to likely be associated with the presence of inspection, the disincentive for private automobile use brought about from increased congestion resulting from reduced capacity in the form of freeway lane-miles per capita leads to the use of more efficient modes of transportation in light of the increased environmental awareness of travelers.

TABLE 1: The Estimated CO_2 Change (metric tons) for a 10% Increase in Each Explanatory Variable

					CO_2 Change				
	Urbanized Area	**CO_2 /cap.**	**Total CO_2**	**Transit Related CO_2**	**Transit Share**	**Freeway Lane-mi/cap.**	**Avg. Travel Time**	**Avg. Priv. Vehicle Occupancy**	**Pop. Density**
Inspection	Anchorage, AK	0.793	216,035	5,971	–	17,821	9,684	–	– 2,824
	New York-Newark, NY-NJ-CT	1.422	25,216,205	3,148,383	–	833,341	1,488,862	–	– 119,854
	Milwaukee, WI	1.518	2,057,127	45,971	–	78,603	67,849	–	– 17,408
	Oxnard, CA	1.532	883,628	183	–	43,264	36,074	–	– 6,541
	LA-Long Beach-Santa Ana, CA	1.558	19,492,406	259,307	–	636,420	804,363	–	– 59,623
	Norwich-New London, CT	2.436	472,353	2,264	–	30,250	8,404	–	– 4,397
	Barnstable Town, MA	2.538	626,825	1,005	–	29,554	15,144	–	– 10,223
No Inspection	Laredo, TX	0.725	142,431	2,699	– 5,022	2,680	25,644	– 69,264	–
	Wichita, KS	0.885	334,041	3,802	– 2,142	16,521	54,372	– 146,810	–
	New Orleans, LA	0.945	953,995	41,983	– 28,978	17,192	180,521	– 383,581	–
	Shreveport, LA	1.512	415,719	5,100	– 1,640	10,979	37,661	– 99,223	–
	Corpus Christi, TX	1.518	447,746	9,024	– 2,324	12,064	40,976	– 110,115	–
	Miami, FL	1.545	7,877,916	216,204	– 81,226	75,380	970,798	– 1,801,744	–
	Albany, NY	2.341	1,227,548	17,947	– 4,425	23,837	81,620	– 194,116	–
	Poughkeepsie-Newburgh, NY	3.191	659,107	4,364	– 827	16,315	73,665	– 125,805	–

Average travel time exhibits similarly strong impacts whether automobile inspection programs are present or not (for 20 of the 70 urbanized areas with inspection programs average travel time has the largest impact) – up to 0.97M metric tons and 1.5M metric tons per year for Miami, FL and New York-Newark, NY-NJ-CT, when average travel times increase by 10% from 28.14 to 30.95 minutes and from 35.15 to 38.66 minutes, respectively – all else equal. Naturally, travel time is strongly associated with the amount of travel, thus, its role in appreciably contributing to CO_2 emissions.

At first sight, the relatively smaller changes in CO_2 emissions resulting from a change in transit share, where the estimated coefficient is significantly different from zero in the absence of automobile inspection, may be surprising. However, it can be seen from Table 1 that the amount of transit related CO_2 makes up a small percentage, usually between 1% and 2%, of an urbanized area's total CO_2 emissions. For this reason, the impact of transit share on CO_2 emissions in terms of the magnitude of the total change is limited compared to the impacts other variables have. Nevertheless, in absolute terms, the effects of transit share could still be larger than that of freeway lane-miles per capita in the absence of inspection as seen in Table 1 in the cases of Miami, Fl, New Orleans, LA, and Laredo, TX. Similarly, the magnitude of the impact of a change in population density, where the estimated coefficient is significantly different from zero in the presence of automobile inspection, is fairly small. Across all 70 urbanized areas considered with automobile inspection, the impacts of changes in population density are much smaller than the impacts of changes in freeway lane-miles per capita and average travel time – by factors exceeding ten for New York-Newark, NY-NJ-CT, and LA-Long Beach-Santa Ana, CA.

Finally, it is noteworthy that the relative magnitudes of the impacts across the different explanatory variables vary by urbanized area within each of the two automobile inspection categories. For example, in absolute value terms, the impact of the change in average private vehicle occupancy is approximately twice that of the change in average travel time for Miami, Fl, while the impact of the former variable is almost three times as much as that of the latter for Wichita, KS. Moreover, the impact of the change in average travel time is almost twice that of the change in freeway lane-miles per capita for New York-Newark, NY-NJ-CT, while the impact of the change in the former variable is approximately half that of the latter for Anchorage, AK. Clearly, the impact that a change in each variable could have on CO_2 emissions for a particular urbanized area depends on the values other variables take for that urbanized area.

4. POLICY IMPLICATIONS

In what follows, the conclusions based on these quantifications are summarized and the corresponding implications of these conclusions are discussed. The implications are not intended to provide prescriptions that apply to specific urbanized areas considered in this study but rather offer general considerations based on the identified overall trends.

- Not surprisingly, changes in average travel time have a substantial impacts on CO_2 emissions whether in urbanized areas with or without the proxy automobile inspection programs. This result validates the importance of focusing on policies aimed at reducing the total amount of travel in urbanized areas as effective measures to mitigate the contribution of passenger travel to CO_2 emissions.

- For urbanized areas with automobile inspection programs, seen as proxies of the presence of GHG-reducing policies or environmentally favourable travel behaviors, the variable that is found to have by far the largest impact on CO_2 emissions based on a given percentage change across all the variables considered in the integrated dataset is freeway lane-miles per capita. This finding implies that, in general, for a given percentage change in any of the variables found to influence CO_2 emissions in a statistically significant manner, freeway lane-miles per capita would be most worthwhile to focus on in formulating policies aimed at reducing CO_2 emissions especially in urbanized areas where aggressive policies aimed at addressing environmental concerns are in place and travellers' attitudes are favourable towards mitigating negative environmental impacts.

- For urbanized areas without automobile inspection programs, again seen as proxies of the effects discussed extensively in this paper, the variable that is found to have the largest impact on CO_2 emissions based on a given percentage change is average private vehicle occupancy. This finding implies that, in general, for a given percentage change, private vehicle occupancy would be most worthwhile to influence in formulating policies aimed at reducing CO_2 emissions especially in urbanized areas where less aggressive policies aimed at addressing environmental concerns are in place and travellers' attitudes may not be as focused on mitigating negative environmental impacts, whether due to limited travel options or not as strong a sense of awareness.

- The relatively smaller magnitudes of impact on reduced CO_2 emissions with respect to transit share increasing by 10% (all else equal) are understandable in light of the fairly low transit share and transit service utilization values across most urbanized areas in the US. In light of the confounding effects of low transit share and transit service utilization, it is important not to undervalue the potential that could be achieved from the increased use of public transportation on reducing CO_2 emissions as at much higher values of transit share and utilization, larger impacts resulting from increased transit use could be achieved.

- A 10% increase in population density (all else equal) results in relatively smaller magnitudes of impact on reducing CO_2 emissions implying that a much larger increases would be necessary to achieve impacts of similar magnitudes brought about through changes in other variables. This result, however, should not imply a undervalue the potential contribution of this variable especially given the possible role that population density could play through land-use policy instruments in facilitating changes in the more impactful variables, such as travel time and transit use.

- The variables that are found to have statistically and appreciably different effects and impacts on CO_2 emissions in the presence and absence of automobile emissions inspection programs, serving as proxies to the effects already discussed extensively, are transit share, freeway lane-miles per capita, average travel time, and average private vehicle occupancy. Not surprisingly, these differences suggest that the development of policies aimed at reducing CO_2 emissions in an urbanized area must be carried out in light of any other policies already in place aimed at addressing environmental concerns and the overall attitudes travellers have towards such concerns.

- Even within each of the two automobile inspection categories, the relative magnitudes of the impacts corresponding to the different explanatory variables vary appreciably across urbanized areas. Such variability implies that policies aimed at reducing CO_2 emissions are likely to have to focus on different variables depending on the overall characteristics of the specific urbanized area. That is, while the findings are in general fairly consistent across urbanized areas, potentially successful policies in terms of actual reductions in the magnitude of CO_2 emissions are likely to be context specific.

5. FUTURE RESEARCH

In the above discussion of the possible implications of the various conclusions through the comparison among the impacts of the changes in various variables, it is assumed that the same percentage change in the variables are achievable. However, the effort involved in achieving a unit percentage change in a variable and the feasible range of variable changes are expected to vary widely across both the various variables considered and found impactful, and across urbanized areas. Therefore, once again, the above implications should not be viewed as policy prescriptions but rather as demonstrations of the potential value of the quantifications arrived at and a motivation for a comprehensive analysis that takes into account the effort involved in achieving favorable changes in the various variables under consideration.

Naturally, policy implications can be assessed to the extent that the model specifications allow. Richer models would, therefore, allow for considering a broader set of possible policies. For example, as already discussed, transit service utilization is expected to be critical in realizing the full impact of changes in transit share on passenger travel related CO_2 emissions. Also, while the effect of transit share is found to be statistically significant for urbanized areas without proxy automobile inspection programs, other variables exhibit stronger effects on CO_2 emissions. To be able to assess the full range of the possible impact that changes in transit share might have, a data set reflecting a wider range of transit share and transit service utilization magnitudes would be valuable. In addition, other potentially important variables, such as those relating to gas tax policy and congestion pricing, are not captured in the integrated dataset considered in this study. Therefore, expanding the dataset to address the above limitations would be worthwhile. Such expansions might include urbanized areas around the world where a higher dependence on transit along with varying urban geographical characteristics and transportation investments and policies exist.

In light of extending the nature and number of variables considered, exploring the joint impacts of variables on CO_2 emissions becomes more critical. In this study, single factor effects are considered, all else equal. However, several of the variables are associated with one another, and therefore, understanding joint effects would be valuable for a variety of reasons. Joint effects could lead to larger combined impacts on CO_2 emissions. For example, changes in the values of freeway lane-miles per capita could influence transit use and lead to larger impacts on CO_2 emissions than would otherwise result from each variable separately all else equal. In addition, while changes in certain variables with statistically significant coefficients may not have appreciable impacts on reducing CO_2 emissions on their own, their role in facilitating changes in other variables leading to appreciable joint impacts may be important. For example, while increasing population density is not found to have an appreciable impact on reducing CO_2 emissions, such an increase could lead to reduced average travel time and increased transit use and, as a result, contribute to overall larger reductions in CO_2 emissions.

The dataset considered is cross-sectional in nature. That is, it does not allow for the assessment of the impact of certain changes in certain variables on CO_2 emissions as they occur in a specific urbanized area. Considering time series effects would greatly enhance the understanding of CO_2 emissions due to passenger travel in light of dynamically varying sets of variables whereby conditions before the implementation of certain policies aimed at reducing CO_2 emissions could be directly compared to conditions in the presence of such policies. However, the compilation of a panel dataset that allows for the study of time-series effects across numerous urbanized areas presents much greater challenges than those discussed in this paper.

Finally, it is important to note that even if rich statistical models are able to capture the complexities involved with data pertaining to a large number of urbanized areas, such aggregate models would still be too gross in nature to support policy making for a specific urbanized area. Nevertheless, such models do offer value. They allow for the quantification of the general effects that specified changes in important variables might have on CO_2 emissions. This provides a tool for policy makers to explore the relative impacts of broad policies, which would guide the customization of specific policies tailored to specific urbanized areas, taking into account contextual considerations through detailed urban land-use and transportation modeling exercises. That is, aggregate models offer gross predictions for a specific urbanized area that bracket the magnitudes of the feasible impacts that could be derived from changes in travel and urban characteristics, thus, either motivating and justifying further detailed analyses and policy developments based on the promising variables, or discouraging certain efforts in light of the limited benefits assessed based the less promising variables.

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APPENDIX

The estimation results of the final model arrived at (Mishalani et al., 2014; Mishalani and Goel, 2015) accounting for selectivity bias are shown in Table A.1.

TABLE A.1: Model Estimation Results

	Inspection				No Inspection			
Explanatory variable	**Coeff**	**Std err**	**t-stat**	**p-value**	**Coeff**	**Std err**	**t-stat**	**p-value**
Constant	0.327	0.675	0.485	0.630	3.373	1.022	3.301	0.002
Transit Share	0.309	1.231	0.251	0.803	– 7.456	4.179	– 1.784	0.079
Freeway Lane-mi/capita	1156.691	116.282	9.947	<0.001	406.307	121.761	3.337	0.001
Average Travel Time	0.024	0.008	2.991	0.004	0.070	0.012	5.814	<0.001
Avg. Priv. Veh. Occupancy	– 0.215	0.571	– 0.376	0.708	– 3.054	0.920	– 3.320	0.001
1/Density	393.198	190.696	2.062	0.043	– 25.158	289.587	– 0.087	0.931
Selectivity Bias Correction	0.034	0.031	1.069	0.289	– 0.081	0.037	– 2.211	0.030
	# of observations = 70; R^2 = 0.732				# of observations = 76; R^2 = 0.519			

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