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Potential Use of Clean-Development Mechanism in
Structuring Cities for Carbon-Efficient Transportation*

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The Kyoto Protocol and Sustainable Cities: The Potential Use of the Clean Development Mechanism in Structuring Cities for “Carbon-Efficient” Transport

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Pedro Donoso
Laboratorio de Modelamiento del Transporte y Uso de Suelo
Universidad de Chile
Av. Blanco Encalada 1975 2° Piso
Santiago, Chile
Tel:/Fax: (562) 697 1757, (562) 699 6852
pdonoso@labtus.cl

Francisco Martínez
Departamento de Ingeniería Civil
División Ingeniería de Transporte
Universidad de Chile
Av. Blanco Encalada 2002, Piso 5
Santiago, Chile
Tel: (562) 6784380; Fax: (562) 689 4206
fmartine@cec.uchile.cl

Christopher Zegras
Department of Urban Studies and Planning
Massachusetts Institute of Technology
77 Massachusetts Avenue
Room 10-403
Cambridge, MA 02141
Tel: 617-452-2433; Fax: 617-258-8081
czegras@mit.edu

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ABSTRACT

This paper assesses the possibility for changing urban development patterns to reduce transportation greenhouse gas (GHG) emissions. The analysis was carried out as part of a larger project exploring the possibility of using the Clean Development Mechanism (CDM) to reduce transportation GHG emissions in Santiago de Chile. The paper provides an overview of the analytical approach, which includes an integrated travel demand model with sensitivity to *meso*-level land use variations, a method to generate optimal land use scenarios with regards to emission reductions, and a process to estimate the level of subsidies needed to produce those land use scenarios. Limitations to the approach and suggestions for future research are discussed. The paper concludes with an assessment of the results in the face of the fairly strict requirements for project development and implementation implied by the CDM.

INTRODUCTION

Interest in modifying urban development patterns to influence transportation energy consumption dates back to at least the first global oil crisis of the 1970s (1). Today, energy security risks continue while the global climate change risk adds further pressures to reduce transportation energy consumption. While the climate change mitigation burden clearly falls to the world's industrialized nations, which account for the overwhelming share of accumulated anthropogenic GHG emissions, the rapidly industrializing countries constitute a large and growing share of global emissions (almost 50%, including the countries of Eastern Europe and the Former Soviet Union; (2)).

In February 2005, the Kyoto Protocol to the United Nations Framework Convention on Climate Change entered into force for signatory countries. The Protocol contains several market-based mechanisms, including the Clean Development Mechanism (CDM), which allows industrialized country governments or private entities to invest in developing country emission reductions. The industrialized country project "proponent" earns emission reductions – known as Certified Emission Reduction units (CERs) – towards domestic targets while the developing country advances its development goals. Indeed, the Kyoto Protocol specifies that CDM projects must help host countries achieve "sustainable development," although the Protocol does not specify a definition of the concept. The market value of a CER varies according to the prevailing carbon price and can be influenced by factors such as country and project risk. In Europe the price per tonne of carbon recently exceeded US\$20.

The majority of CDM projects to date have focused on renewable energy, energy efficiency, and landfill gas projects. As of early 2005, of roughly 1200 CDM projects under development, just over 200 had reached the project design document (PDD) stage. The PDD represents the first step in the CDM process, formally defining the project, estimating emissions reductions, and describing the monitoring plan. Of those 200 projects, just four were transportation projects (3).

Transportation remains an important and challenging GHG emissions sector to address: it accounts for approximately 30% of anthropogenic GHG emissions, is growing rapidly, and has highly dispersed emissions sources (e.g., individual vehicles) with few readily available, less carbon-intensive energy substitutes. More broadly, transportation clearly plays an important role in sustainable development. In the case of passenger transportation, for example, transportation provides access to jobs, education, social opportunities, etc. – fundamental to human development. At the same time, however,

transportation often imposes impacts, in the form of air pollution, accident risk, etc. that pose a serious threat to sustainability.

While detailing the numerous CDM project requirements extends beyond the scope of this paper (see 3), three critical CDM-specific aspects bear mentioning here, due to their importance to our analysis:

1. the project baseline, which must represent a defensible vision of future emissions relative to “business-as-usual”;
2. additionality, which refers to the requirement that emissions reductions be *additional* to what would have taken place in absence of the project; and
3. monitoring and verification, which refers to the need for external monitoring and verification of emission reductions.

This paper presents results of an effort to assess the potential of the CDM to reduce GHG emissions from the transportation sector in Santiago de Chile. The paper analyzes a decidedly behaviorally-based intervention: the possibilities for modifying urban development patterns to reduce GHGs via changes in passenger travel demand. LABTUS (4) presents a more detailed exposition of the theoretical and technical underpinnings of the analysis..

TRANSPORTATION AND THE CDM: WHY LAND USE?

This CDM analysis rests on the basic premise that influencing land use patterns produces changes in individual travel behavior, thereby influencing transportation greenhouse gas emissions (GHGs). In contrast to typical CDM projects, this initiative differs in a *fundamental* way by aiming to change individual behavior. In this sense, the approach faces methodological and implementation hurdles relative to technology-oriented CDM projects, for which estimated GHG emission impacts are (relatively) straightforward to calculate and verify. In the land use case, we expect changes in land use to influence the distances people travel, as well as the relative attractiveness and the occupancy of different modes. Since these effects are *behavioral* and, in some cases, depend on second order influences, estimating their impacts requires modeling techniques that introduce uncertainties.

Despite the challenges, behavioral change may have to play an important role. For example, Heywood et al’s (5) recent assessment of transportation energy consumption under plausible vehicle technological improvements in the US market leads to the “sobering overall conclusion” that technology improvements *and* reductions in travel growth are critical. For the developing countries, we expect rapid growth in vehicle ownership and use, with expected growth rates in per capita light duty vehicle kilometers traveled (VKT) on the order of four to 30 times higher than OECD countries (6). These rapid growth rates signify an important amount of “catching up” – in 2050, per capita VKT in North America will still be 3 times higher than in Latin America (6). While we cannot reasonably expect the developing countries to simply curtail transportation demand, absent a technological “silver bullet” some reduction of VKT growth may well be necessary in both the industrialized *and* the developing world.

This reality leads to an examination of the role of urban structure in reducing VKT growth. Beyond the potential global benefits, efforts to change urban development patterns offer potentially important long-term co-benefits, such as open space preservation, improved air quality and public health, reduced needs for transportation infrastructure investments, etc. In the face of continuing urbanization prospects, interventions in urban structure could bring

quality of life improvements for nearly 2 billion *additional* developing country urban dwellers by 2030 (7).

Analytical Precedents

Land use interventions have long been of interest as a way to influence travel demand, with multiple reviews of relevant analyses carried out over the years (e.g., 1, 8, 9). The multiple studies reveal somewhat wide-ranging estimates of effects, which can be partly attributed to differences in approach (e.g., spatial scale of analysis, analytic technique), the types of built environment measures used, and the effects (e.g., mode choice, trip rate) analyzed. Recent years have seen a push to base the relevant research within more rigorous behavioral theories (e.g., 10) which closely aligns with “traditional” transportation systems analysis (e.g., 11). Most recently, analysts have made the explicit turn to random utility theory-based discrete choice models (e.g., 12).

In the late 1960s, several precedents emerged in the form of simulations, looking specifically at the potential for alternative city structure to influence transportation patterns, primarily in the form of experimental analyses of “hypothetical” cities (e.g., 13). Continuing advances in computational power and the 1970s energy crises spurred many analyses of how altering “spatial structure” could reduce transport energy consumption (e.g., 14). These efforts, in most cases, utilized techniques similar to the traditional travel forecasting models (or Lowry-based integrated models), but with the goal of identifying generic, energy efficient, urban forms. The typical result was the heavily CBD-focused city, or the “polynucleated” form (e.g., 15). Relevant, energy use-focused simulations (e.g., 16) as well as empirical analyses (e.g., 17) continued into the 1980s.

In more recent years, forecasting models have been applied to real cities to gauge the possibility of using land use strategies for influencing travel demand. In the United States, the pioneering effort was the LUTRAQ project, in the Portland (Oregon) metropolitan area. LUTRAQ utilized integrated land use and travel demand models to assess the possibilities for using alternative urban forms as a possible alternative to developing a new highway (18). Other studies have followed somewhat in the LUTRAQ tradition in the U.S. (e.g., 19, 20).

Policy Implications

Even if we can confidently predict the influence of land use on travel behaviors, the ability to influence relevant outcomes hinges critically on the institutional and policy setting. The United States experience with local air pollution offers an interesting precedent, in particular the need to ensure state conformity with air quality regulations. US EPA (21) guidelines suggest that land use can be included as a transportation air quality control strategy if the effects are quantifiable, surplus (i.e., “additional”), enforceable, permanent, and adequately supported. Such requirements suggest a direct precedent for the relatively stringent project-based requirements of the CDM. At least one project, the proposed redevelopment of a 138-acre former steel mill site in central Atlanta (Georgia), offers a promising precedent: modeling techniques were used to predict both *meso*- and *micro*-level influences (estimated to achieve reductions on the order of 15 to 67% and 4 to 6%, respectively) (20); and the project developer agreed to several monitoring, verification and contingency measures (22). Still in early development stages, the project’s transport air quality effects cannot yet be evaluated.

EMPIRICAL CASE: SANTIAGO DE CHILE

Background

In Chile roughly 85% of the nation's population lives in urban areas. Still, even moderate future urban growth has important implications. For example, a 1.25% annual population growth rate in the Santiago Metropolitan Area would imply an additional one million new households locating in the city over the next 30 years. Given current urban growth trends – from 1985 to 1995, the urban area expanded 70% more rapidly than population growth (23) – the distribution of future population growth and related land uses will greatly influence underlying urban travel behavior for generations of *Santiaguinos*. Today, the contiguous urban area of Greater Santiago's 38 municipalities covers approximately 80,000 – 90,000 hectares (800-900 square kilometers). The gross population density is roughly 65 persons per hectare, while the net (of, e.g., roadways, open space, etc.) population density is on the order of 85 persons per hectare.

Multiple, often inter-related factors have contributed to Santiago's urban growth patterns in recent years (see 23), including income growth, motorization, space demands and subsequent suburbanization pressures. These are mutually reinforced by real estate company growth and land speculation. Transportation infrastructure development plays a clear role, expanding urban edge access. Another expansionary pressure comes from continuous demand for lower-income housing, typically located on the urban fringe. Public policy initiatives have produced somewhat countervailing effects. For example, an urban renovation subsidy program has created incentives for the development of some 22,000 new apartments in the central city since 1992. At the same time, a 1997 modification to the metropolitan land use regulatory plan, opened up almost 20,000 hectares for urban development in the rapidly suburbanizing north. Recently, the World Bank supported "Sustainable Transport and Air Quality Project," included a "location efficiency" component, a concept still in initial stages of development.

Data

The primary data underlying the analysis come from the 2001 origin-destination (O-D) survey and the land use census, carried out and compiled under the auspices of national transportation planning authorities (SECTRA) (see, e.g., 24). Estimating the model required approximated transportation costs for all origin-destination pairs for all mode types, which were derived from a previous (2001) transportation model run (using SECTRA's travel forecasting model, ESTRASUS). Vehicle occupancy factors, vehicle types, distances traveled, and average speeds are derived from ESTRASUS, the household O-D Survey and related surveys (e.g., traffic counts) carried out complementarily to the O-D survey. Emissions factors come from a locally-developed vehicle emissions model (MODEM).

Methodology

The preliminary empirical analysis of the 2001 O-D survey suggested three basic strategies for intervention: (1) increase non-motorized transport (NMT) for non-work trips by locating shopping and services closer to residential areas (Figure 1 shows the NMT dominance for trips under 1.2 kilometers); (2) increase non-motorized transport for school trips by allocating schools closer to residential areas; and (3) increase public transport usage for medium- to long-distance trips.

Transport Demand and Emissions Model

The transport demand model consists of a set of discrete choice models (multinomial logit models) of trip generation, distribution, and mode choice. The model was specified for and estimated on AM peak period, work day travel, since available transportation level of service information was only available for that period. Figure 2 presents the basic transport demand model framework, with trip generation (production and attraction) at the upper (root) level, and trip distribution conditional on trip generation, and mode choice conditional on trip distribution. The inclusive values from the lower level nest serve as indexes of relative utility in the higher level nests. In this framework, certain parameters (represented by θ) are users' fixed taste parameters, while α and β vary to represent different land use conditions.

The model does not consider route assignment, due to limitations in available resources and time. But, the modeling framework allows for expansion to include route assignment, as well as to analyze relevant transportation management measures such as parking pricing/availability, changes in levels of service, etc. The lack of route assignment in the current application implies that the levels of service of the transport modes are invariant when land uses change; the only exception to this is the case of walking, for which we included an empirically-derived trip distance effect (walking accounts for 37% of all weekday trips and 23% of AM peak trips). This simplification also implies that average speeds – derived from observed data and independent of route, zone, or time of day – were used to calculate GHG emissions.

Despite these simplifications, the model performs fairly well. Modeled emissions exceed actual (observed) by 21%, due primarily to overestimates of private transport emissions, which account for nearly 80% of total emissions (bus accounts for 15%). The model has a tendency to overestimate the number of longer distance trips (see Figure 3).

Optimization and Land Development Subsidy Models

The travel demand model simulates system equilibrium, building from the relationships observed in the travel survey and the land use census to predict how future travel patterns will evolve under different land use scenarios. A second stage model uses an optimization procedure, with the goal of minimizing emissions reductions (details on the specification and procedure can be found in 4). This process relocates activities (households and firms) so that the associated expected transport demand (aggregated across modes, purposes and periods) minimizes the expected emission totals (considering observed emission rates for 30 different vehicle types). Different activities' location patterns influence trip demand by affecting trip generation and trip attractions.

From the optimum location pattern, a third model calculates the subsidies required to make households and firms locate according to the “optimized” city. This model is based on the urban equilibrium theory used in MUSSA (the Santiago land use model; see, e.g., (25, 26)), simulating a process of real estate auctions with stochastically behaving bidders. The method to calculate the subsidies consists of inverting the location model on prices and replacing in the resulting formula the optimal allocation pattern – the inverse of the allocation model's normal process. Thus, the estimated optimal subsidies reconcile the auction equilibrium with the optimum location pattern. The equilibrium approach makes all agents' interactions explicit – as represented in their bid functions, including location externalities (e.g., neighborhood quality represented by the average income of residents and zonal building density) and firms' agglomeration economies (including reduced production costs

via firm concentration and increases in clients' travel costs). These take on particular relevance for computing optimal subsidies; they are economic forces that induce differential prices across space, directly affecting the required subsidies. The modeling framework enables the consideration of a range of relevant land planning interventions, such as changes in zoning codes, density allowances, etc. Altogether, the approach (e.g., the inverse process, the consideration of externalities and planning regulations), involves solving a set of non-linear simultaneous fixed-point equations, requiring an ad-hoc converging algorithm developed in the study.

As such, we model travel distances and the spatial distribution of activities in an integrated fashion, accounting for relevant factors influencing residential and non-residential location decisions. Except for route assignment, the model considers the full set of relevant choices: residential and firm location and passenger travel demand. The model produces, for given time periods, a land use-transportation equilibrium – a non-trivial accomplishment given the multi-dimensionality of the problem and the non-linearity associated with the interdependency between location choices and between the location pattern and trip choices, including the effects of land rents.

Application

The model considers 409 ESTRAUS zones, 13 household categories (stratified by income and auto ownership), three trip purposes (Work, Education, and Other), and 11 modes (including combinations with subway). We employed the model to: (1) establish the baseline, which assumes trend growth in travel demand as a function of household growth (estimated at 1.47% annually) and concurrent growth in residential and non-residential land uses; and (2) estimate travel emissions reductions resulting from several scenarios of meso-scale changes in household, educational, and other land uses. Emission reductions derive directly from reduced VKT, due to a shift from motorized to non-motorized travel and changes in trip destination choices.

We analyzed the emissions effects of several alternative land use scenarios: (1) the “pre-optimal” scenario, represented city performance under an optimal land use re-location – providing something of an “upper limit” of potential emission reductions without regulations on future land use patterns; (2) the “education-oriented” scenario relocated educational facilities directly proportional to residential location patterns; (3) the “non-residential-oriented” scenario redistributed non-residential land uses proportional to residential location patterns; and, (4) the “sub-center scenario” concentrated a high share of residential and non-residential land uses into defined sub-centers on the urban edge. We built Scenario (1) using the optimal model and defined the others according to the aforementioned criteria. The subsidies estimated were “demand-side” subsidies (i.e., those required to induce changes in households' and non-residential land users' locational decisions); in this sense, the subsidies work in a way similar to the urban revitalization subsidies mentioned above.

The modeling assumed that the various land use scenarios could be realized within a five year period, possibly an unrealistic pace of change given the magnitude of the restructuring implied and the inertia of current trends (and existing land uses). In the case of slower implementation, the total present value of benefits to a project proponent would be reduced. This could be troublesome for a project with a proposed short (e.g., seven year) time-frame. Under the CDM, projects may be undertaken for a fixed period of ten years or in three renewable periods of seven years each (to a total of 21 years).

We modeled each of the first five years, calculating the difference between the project and baseline emissions. After the fifth year, the differential emission reductions (achieved at year five) are assumed to perpetuate. The ultimate impacts of the land use changes would certainly extend well beyond year five, as the built environment and related transportation behavior would endure for at least a generation. We include these extended effects in the results presented below.

Two important points arise regarding the application. First, we worked with the 409 zones from a previous version of ESTRAUS because at the time data on inter-zonal levels of service (for model calibration) were only available for these zones. The size of many of these zones may mask local- (zonal-) level influences on travel behavior. Recent analysis has shown some influences of, for example, dwelling unit density and land use mix on pedestrian and public transport mode choice in Santiago, after controlling for inter-zonal levels of service; these effects vary, however, according to trip purpose (see (27)). Second, in this application, we looked solely at the use of subsidies to achieve the four land use scenarios – other mechanisms (e.g., zoning) could be used to achieve the same results. The modeling framework allows the consideration of a range of planning alternatives.

Results

The analysis produces the following emissions reductions relative to the baseline: education, 12%; non-residential, 21%; sub-centers 40%; and the “pre-optimal” scenario, 67%. At year 10, cumulative emission reduction estimates range from 4.4 million tonnes to 21.1 million tonnes; at year 21, the estimated cumulative reductions range from 11 million to nearly 57 million tonnes (See Table 1). The relatively high total reductions apparently obtainable under both the pre-optimal and the sub-center scenarios represent extreme upper bounds: the significant city restructuring implied in these scenarios make their implementation unlikely-to-impossible. The estimated subsidies that would be required to achieve these scenarios reflect this: US\$5 billion over five years in the sub-center case and US\$15 billion in the pre-optimal case.

On the other hand, the estimates suggest that the relatively more moderate emission reductions in the education-oriented scenario and the non-residential scenario could be more viable. In fact, the education scenario appears feasible, with the required subsidies implying a cost under US\$10 per tonne over a seven year time frame. Bear in mind that the subsidies restructure the city, implying permanent travel demand changes. As such, extending the project lifetime tends to reduce estimated total costs per tonne (see Table 1). If implemented under a single 10-year accreditation period, the education-oriented scenario would be an attractive CDM investment at current CER market values.

Strengths and Limitations

One must view the above results as preliminary for any CDM application, given the analytical and data limitations. In terms of data, the major problems arose from the lack of necessary information (i.e., changes in travel costs) regarding impacts of future proposed transportation interventions, hampering “true” baseline estimation.

We must recognize that any practical effort to model the complex urban system must simplify in at least some relevant dimensions, which naturally produces uncertainty in predictions. In this case, lack of data and time required that the model focus on home-based trips made during the AM peak period of a normal work week. Using expansion factors, this

period is extrapolated to represent the entire year. While roughly consistent with current travel forecasting practices in Santiago, this extrapolation may be a source of inaccuracy (worth removing in a more detailed study). For example, the majority of household shopping, recreation and social trips occur during off-peak periods and/or on weekends and such trips may have different travel patterns than those modeled during the AM peak. The trip-based focus also made it impossible to account for potentially important influencing factors, such as trip-chaining. Furthermore, as mentioned above, potential local level effects (i.e., beyond those captured by inter-zonal levels of service) on, e.g., mode choice, are not accounted for in this application.

The modeling did not include actual network performance (route assignment), thereby not accounting for, for example, changes in vehicle speeds which not only influence emissions but also potentially influence mode choice and/or trip generation. In terms of the influences of land use on mode choice, the modeling approach ultimately only captures the effect of trip distance changes on walk trips (and subsequent substitution for motorized mode trips). This ignores potentially important effects, such as the variation in vehicle occupancy rates brought about by land use changes. A related simplification stems from the complexity in estimating the emissions effects from changes in demand for different modes, such as bus or taxi. In the model application, we assume bus fleets and frequencies adjust quickly to demand, thereby producing emissions reductions. Also, we have excluded the impacts on commercial/freight traffic. Finally, and importantly, we have not accounted for the impacts of the scenarios on so-called “co-benefits” (such as travel time reduction, air pollution improvement, open space conservation, etc.).

The above-mentioned limitations to the modeling must be viewed in light of the accomplishments. We attempted a “complete” model of the city, one that could account for the interactions within the land market and between the land market and the transportation system. In this way, consistent choice patterns arise from actual prices and costs within the system and the calculated subsidies reflect the “summary” of a number of complex pecuniary and technological forces. The optimization procedure that searches for the land use pattern that generates transport demand with the lowest possible GHG emissions considers all choices (except route assignment), including: modes, trip destination, location, and building supply.

Possible Extensions and Refinements

With additional time and resources several useful extensions to this work could be undertaken, such as:

- including multimodal transportation network assignment and link-by-link performance;
- extending the analysis to off-peak travel, weekend travel and trip chaining;
- incorporating commercial traffic;
- including potential evolution in vehicle technologies;
- assessing more thoroughly the influence of *micro*-level urban design on travel behavior;
- improving the evaluation methodology to fully include all social benefits and costs (i.e., the “co-benefits”);
- developing a vehicle ownership model sensitive to land use variations (e.g., 27);
- expanding the model’s spatial context, to account for current rural and semi-rural areas; and,

- generating a set of feasibility and policy constraints to produce more realistic land use patterns and rates of change.

IMPLICATIONS AND LESSONS

If we want to effectively intervene in city structure utilizing an instrument such as the CDM (with its stringent requirements regarding baselines, etc.), then we confront challenges due to the time and resources required to develop adequate analytical tools and collect the necessary data. Furthermore, we cannot ignore the importance of institutional capabilities (i.e., a fully responsible, empowered, and accountable agency) to implement such an initiative.

Nevertheless, this analysis has shown how urban policies can be analyzed with the goal of diverting from the “do-nothing” city towards a more sustainable urban future.

Our preliminary results show some promise. In the case of the education scenario, the estimated subsidies required to achieve the changes in land uses indicate potential CDM feasibility. A major uncertainty in this case stems from the degree to which consumer demand (for educational opportunities) would comply with the model predictions, requiring more detailed modeling on school quality choice. In the case of the non-residential scenario, the costs per tonne escalate, in the range of US\$91 to 150 (see Table 2). However, in both scenarios the value of additional and possibly significant co-benefits could reduce the per tonne costs.

The results underscore a challenge: people and companies would apparently demand significant compensation (measured by subsidies) to change their location behavior to induce more “GHG-efficient” travel patterns. This result should not be surprising; travel behavior figures only moderately in most households’ residential location choices and, quite often, in choices about where to shop or send children to school (e.g., 28). Our modeling suggests that inducing transport change through land use interventions requires fairly strong incentives. These estimates derive from preferences as revealed through the 2001 travel survey and related information on land uses and prices. These preferences might change in time, thereby changing the value of the required subsidies; the role of changing people’s attitudes and their impacts on behavior should not be ignored (e.g., 29).

Despite certain technological improvements, vehicle fuel efficiency gains will not likely be capable of solving, on their own, the GHG challenge in the face of continuing VKT growth (e.g., 5). Some reduction in motorized transport demand may well remain necessary; even if a “silver bullet” to transportation’s emissions problems could be found, cities would still face the problem of ever-increasing amounts of land dedicated for transportation infrastructure in lieu of, for example, public spaces. Rapidly growing cities face, arguably, a more acute urgency – inattention now to land use as a travel demand management measure locks cities into systems with fewer options: a car-dependent city cannot easily break its car-dependency, physically, functionally or culturally.

The CDM and Beyond

The current CDM modalities and procedures imply very detailed analytical capability to understand the multiple interactions, second order effects, and unanticipated consequences that may arise from attempting to influence land uses for achieving measurable transportation GHG reductions. In practice, the CDM requires accurate quantification of GHG savings, imposing a very high bar when it comes to managing urban form for transportation CDM credits. We know that changing land use patterns will change travel behavior; but these

effects are quite difficult to quantify and make permanent. The approach detailed here has taken a city-wide perspective under the assumption that one must aim to capture the complete effects, including location externalities and agglomeration economies.

Nonetheless, a city-wide modeling approach still poses challenges, including those related to modeling complexities and data and resource requirements. Larger questions, regarding system boundaries, also exist. For example, the case modeled here did not include areas of potential future urban expansion; the locations of all future residential and non-residential activities were spatially constrained to the existing urban area. In this case, the project results depend critically on future authorities and their willingness and ability to enforce current regulations regarding areas for urban expansion. This raises questions regarding the reliability of foreseeable future urban planning regulations – critical questions because the estimated subsidies are conditional on the assumed planning scenario. Broader boundary issues could also be raised. For example promoting certain development patterns in Santiago may induce relevant demands in other urban markets in the country, with implications for transport GHG emissions. While not unique to this type of project, the question of “where to draw the boundaries?” needs to be explicitly recognized since we are looking at a global contaminant.

Additionality

Additionality in this case poses another challenge. No policy of such broad coverage as that envisioned in any of the modeled scenarios currently exists, although the Transport Plan for Santiago (PTUS) contains three relevant programs: one focusing on educational facility location, another on new areas of commercial and services, and one on changing residential location trends. It is not clear whether the existence of these announced programs thus constitute a violation of the additionality concept (none of the relevant PTUS programs currently exists in detail in terms of mechanisms to be used, etc.). A related challenge stems from the potentially changing baseline, since land use regulations evolve and these modifications can be implemented by various levels of government (see 23).

Institutional Responsibility

This last point highlights the considerable implementation doubts arising from the institutional side, largely due to unclear formal policies and the multi-jurisdictional, multi-sectoral government structure covering the relevant sectors. The initiative envisioned here could most feasibly operate as a unilateral CDM initiative, with a city-wide authority establishing concrete goals for achieving transportation emission reductions and selling the resulting CERs. The relevant authority could determine which urban development projects contribute to achieving those goals and reward them appropriately. The authority would also ultimately bear responsibility if the emission reductions were not fulfilled.

Monitoring and Verification

For the project proponent and any interested investor, success hinges upon accurate monitoring and verification (M&V) of emissions reduced. In this case, while the model provides an ex-ante estimate of the emission reductions, the proof rests in ex-post validation. No straightforward M&V program likely exists; perhaps the most reasonable would be annual surveys (household O-D surveys, intercept surveys, and land development surveys), designed specifically to gauge whether land uses and travel patterns are responding as

expected. Land development could be monitored at least in part via existing building permit issuances and tax records (complimentarily to authorities' existing activities). Using annual travel surveys for M&V may fit well with existing Chilean government plans to implement a continuous travel survey instrument for Santiago (24). In theory, this survey instrument could be adapted to satisfy the CDM, requiring, nonetheless, non-trivial decisions on the part of CDM authorities regarding acceptable levels of confidence. Since the survey would ostensibly be financed by the CER seller, this might be an attractive benefit to local authorities. Indeed, enhanced local data collection could be a strong "co-benefit" to host countries. Given the emissions reductions estimated (in, e.g., the education scenario), the required resources for a survey instrument (perhaps US\$250,000-\$500,000 per year for 5,000 households) could be accommodated within the estimated revenue stream – implying, in the case of a 10 year project lifetime, an additional cost of less than US\$1 per tonne.

Project Lifetime and Benefit Accumulation

Essentially, all of the scenarios exhibit declining costs per emissions reduced in time. So, any project proponent would have the incentive to target the longest possible project lifetime. In the case of the three 7-year renewable project lifetimes, the project baseline must be updated at the time of project renewal. This offers an opportunity to "check" the effectiveness of the project and possibly even qualify for more (or less) emissions credits than those initially estimated. Nevertheless, subsequent project assessment can only observe actual urban development with the project since the baseline is unobservable.

In terms of assessing long-term benefits, one must recognize that this project involves durable goods that induce subsequent real estate and transportation investments. In other words, the project defines a specific future path for the city, departing from the baseline with no return. Thus, the project has a far from negligible residual value: a significant share of the city's infrastructure, plus social, economic and environmental impacts. While difficult to assess (in magnitude and sign, i.e., benefit or cost), these impacts may exceed the value of the total GHG reduction. Direct application of standard cost benefit analysis for such a project is probably inadequate.

Final Comments

Our analysis shows that under the current CDM rules and global CER market, location efficiency may prove a viable CDM option, but not without analytical and institutional complications. In terms of institutions, in Chile (or elsewhere) no all-encompassing government with authority over all relevant land use or transportation changes exists. As such, while this initiative requires city-wide implementation, agency accountability remains unclear. Nonetheless, the ongoing urbanization process and the long-term travel behavior patterns embedded in the resulting development patterns suggest the need for ways of combining the local and global. To adhere to its dual goals of reducing GHG emissions *and* promoting sustainable development, a CDM focus on defining more sustainable city futures is critical: a city's development today dictates the city of tomorrow, not only in terms of, e.g., infrastructure development, but also its induced culture.

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LIST OF TABLES AND FIGURES

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TABLE 1 Cumulative Tonnes (millions) Reduced and Cost per Tonne (US\$) Under the Different Scenarios and Project Time Periods

| Scenario | Item | Year 7 | Year 10 | Year 14 | Year 21 |
|------------------------|-------------------|-------------------|--------------------|--------------------|--------------------|
| <i>Education</i> | Cumulative Tonnes | 2.8 | 4.4 | 6.6 | 10.9 |
| | Cost per Tonne | 9 | 6 | 4 | 2 |
| <i>Non-Residential</i> | Cumulative Tonnes | 5.4 | 8.1 | 11.9 | 19.4 |
| | Cost per Tonne | 147 | 139 | 121 | 91 |
| <i>Sub-Centers</i> | Cumulative Tonnes | 8.6 | 13.6 | 20.7 | 34.6 |
| | Cost per Tonne | 921 | 848 | 724 | 538 |
| <i>Pre-Optimal</i> | Cumulative Tonnes | 12.7 | 21.1 | 33.2 | 56.5 |
| | Cost per Tonne | 2,930 | 2,989 | 2,645 | 2,014 |

NOTES: Cost per tonne calculated based on estimated cumulative emissions reduced up to the indicated year, using the present value of the total subsidies required (over the corresponding project implementation period) to achieve the Scenario. The estimated costs exclude monitoring and verification costs, which would imply higher costs per tonne for future years

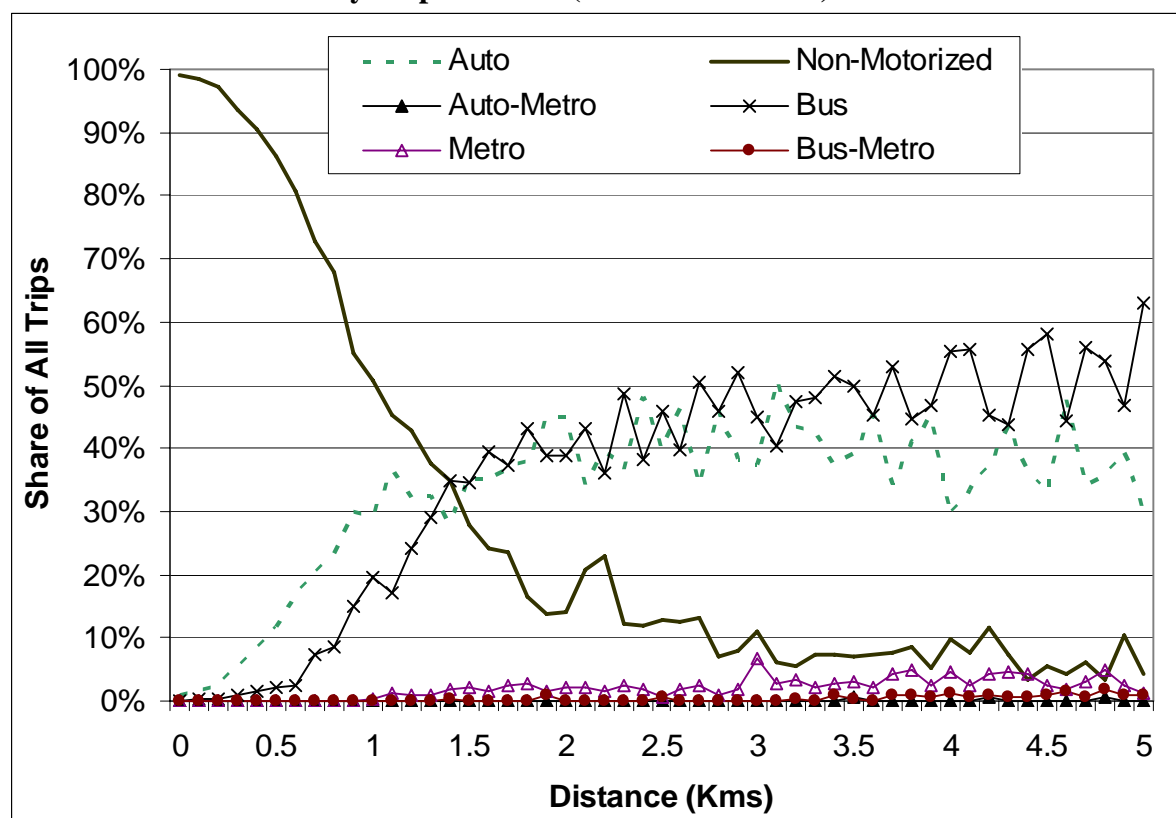
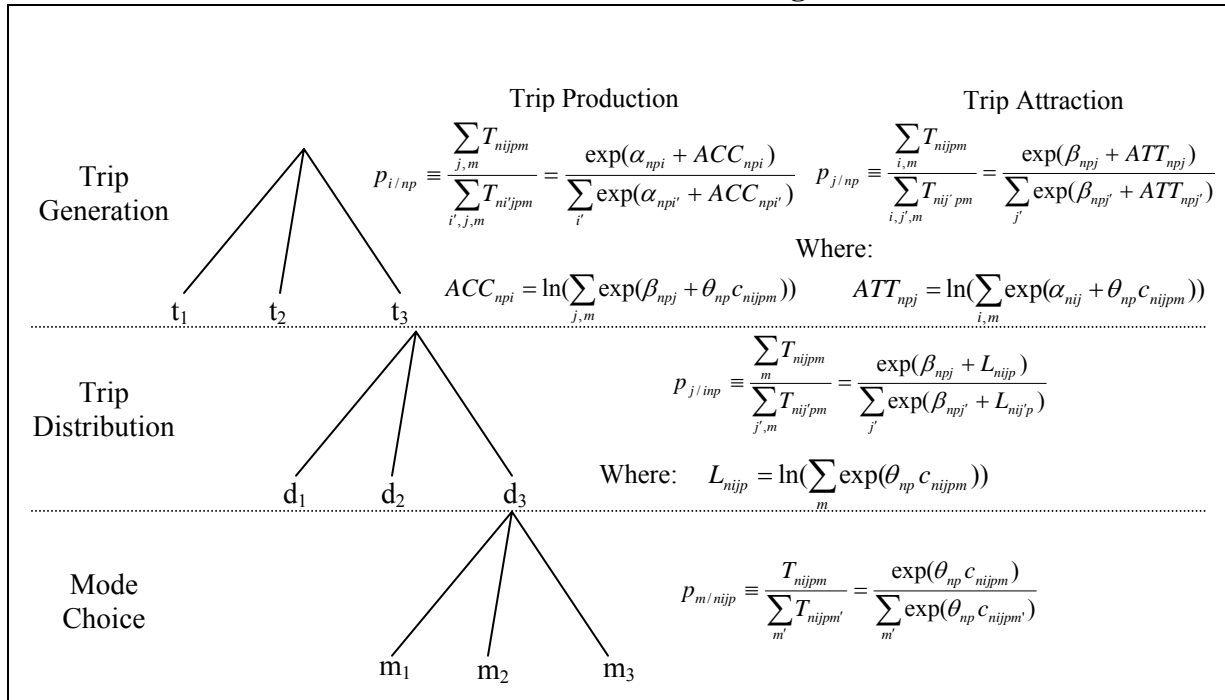
FIGURE 1 Mode Share by Trip Distance (first 5 Kilometers)

FIGURE 2 Multi-Dimensional Travel Demand Modeling Framework

Where:

T_{nijpm} : Number of trips in transport mode m , with trip purpose p , generated at zone i , with destination in zone j , made by a trip-maker from household type n .

c_{nijpm} : calibrated trip cost parameter from zone i to zone j , for trip purpose p , by mode m , made by a trip-maker from household type n .

θ_{np} : Lagrange multiplier, derived from an Entropy Maximizing-Based Travel Demand model, for the constraint matching observed trips to modeled trips by persons in household type n , for trip purpose p , per mode and per zone.

β_{npj} : Lagrange multiplier, derived from an Entropy Maximizing-Based Travel Demand model, for the constraint requiring all trips by persons in household type n , purpose p , to have a destination, zone j .

α_{npi} : Lagrange multiplier, derived from an Entropy Maximizing-Based Travel Demand model, for the constraint requiring all trips by persons in household type n , purpose p , to have an origin, zone i .

FIGURE 3 Modeled versus Observed Work Day Peak Hour Trips by total Distance Traveled

