Escuela de Gobierno y Transformación Pública
Tecnológico de Monterrey

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Steven W. Popper
swpopper@tec.mx
School of Government and Public Transformation, Tecnologico de Monterrey

Juan Antonio Robledo Lara
juan.robledo@tec.mx
School of Government and Public Transformation, Tecnologico de Monterrey

Jonathan Lamb
jlamb@prgs.edu
RAND School of Public Policy

School of Government and Public Transformation

Working Paper No. 43

Publication update: September 2026

Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 00 (2023) 000–000

Procedia Computer Science

www.elsevier.com/locate/procedia

Complex Adaptive Systems Conference 2026

Emergent systems, complexity science, and contested public choice: Housing supply in Monterrey (Mexico)

Steven W. Popper,[a]* Juan Antonio Robledo Lara,[a] Jonathan Lamb[b]

[a]*Escuela de Gobierno y Transformacion Publica, Tecnologico de Monterrey, 756 Av. Revolucion, CDMX 01700, Mexico*
[b]*RAND School of Public Policy, 1776 Main St., Santa Monica, CA 90407, United States*

Abstract

Moving complexity science toward application faces two challenges. Models of adaptive emergence are ill-suited to analytical modes that presume model-based predictability and technical means are insufficient for problems in which normative issues make the problem intractable. Application value will be enhanced within purpose-built frameworks treating such problems' full dimensionality. We offer an example of such a framing for the "wicked" problem of housing in Monterrey, Mexico.

When system transformation is the objective, wicked problems arise in which knowledge, values, and even problem definitions and goals are contested. Solutions are not clear-cut and are themselves emergent processes. Treatment of wicked problems involves deliberations among stakeholders, adaptation, sharing alternative visions, and collaborative problem reframing for effective policy discussions. Ideally, any analytical support should occur within an integrated "deliberation-with-analysis" process. Yet, putting these ideas for decision support into practice faces methodological and practical challenges. The paper lays out both challenges and possible responses. The work on housing policy in greater Monterrey, Mexico, presents an integrated approach to address both aspects of any wicked problem: the technical (non-linear feedback, emergence, self-organization, deep uncertainty) and the value-based (competing interests and assumptions). We employ VSCARP (Visions, Strategic Concepts, Assumptions, and Robust Pathways) among a disparate group of community representatives to conduct participatory foresight that also generates design criteria for model-based quantitative analysis to support further deliberations.

A Monterrey-specific urban model, based on the novel ECLIPSE (Endogenous City Landuse and Integrated Policy Experiment) agent-based framework, is designed for complex computational experiments within a robust decision-making (RDM) experimental design. Rather than conducting two consecutive processes linearly, analysis and stakeholder discussions occur simultaneously in a repeating cycle. This allows people to learn together how the system works, what values are vulnerable to shocks or trends, and which short-term actions are consistent with long-term goals across alternative future pathways. The project is a testbed for gathering insight into how complex systems theory, decision making under deep uncertainty (DMDU) concepts, and social science constructs may be applied to a highly contentious, real-world setting—a *technology* of complexity.

* Corresponding author. Tel.: 52 55 9177-8192
E-mail address: swpopper@tec.mx

Peer-review under responsibility of the scientific committee of the Complex Adaptive Systems Conference with Theme: Adaptive Futures: Theoretical Foundations and Emerging Practices in Complex Adaptive Systems

Keywords: Complex adaptive systems; wicked problems; robust decision making (RDM); participatory foresight; agent based modeling; urban modeling; policy planning; deep uncertainty; Mexico; housing, decision making under deep uncertainty (DMDU); decision support

1. Introduction

If we begin with certainties, we shall end in doubt. But if we begin with doubts, and are patient in them, we shall end in certainties. –Sir Francis Bacon [1]

Complexity science seeks to understand how large-scale complex, organized, and adaptive behavior can emerge from simple interactions among agents [2]. Model building is a leading tool for exploring adaptive interaction [3]. But efforts to move this science toward application, to develop a *technology* of complexity, is hampered by two factors [4]. Models that were deliberately intended to display adaptive system emergence and agent behavior are ill-suited to analytical modes that presume a need for prediction-based analyses. Further, the technical means provided by modelling are alone insufficient to address a category of "wicked" problems [5] whose social aspects go beyond historical context and are, in fact, at the heart of what makes the problem intractable by using more predictive analytical modes. We argue that the potential application value of complexity science will only be elicited within a purpose-built framework that recognizes and treats such problems' full dimensionality. It offers an example for such a framing.

Wicked problems of public policy share two principal elements. One is a tangle of many elements that almost invariably possesses the classic hallmarks of a complex adaptive system (CAS): emergence, path dependence, non-linearities, self-assembly, etc. The second is a contentious decision environment with clashes between different bodies of experience, assumptions regarding the future, and normative valuation criteria: it takes people to create a wicked problem. Contemporary problems of public policy frequently possess this character.

Wicked problems are rarely "solved" definitively. They are instead managed, coped with, or partially tamed through iterative governance – a style at odds with traditional processes of public policy decision making. Recent scholarship sees limits in resolution-oriented processes and instead advocates adaptive management and institutional learning [6-8]. In convergence with CAS study insights, solutions are emergent and co-evolve with problem understandings rather than preceding them; government responses develop contingently as actors grapple with uncertainty, conflict, and interdependence [9, 10]. Problem framing is often a prerequisite for coordinated action because wicked problems are socially constructed and contested ([11, 12]. Such reframing is necessarily a collective and deliberative process requiring engagement among diverse actors whose perspectives shape both diagnosis and range of feasible responses [6, 7]. Even if "wickedness" is not considered an intrinsic property, such problems nevertheless possess epistemic and political dimensions [13].

Traditional approaches premised on stable problem definitions, technical optimization, and definitive solutions are ill-suited to value pluralism, deep uncertainty, and institutional transformation. They assigned problems to single-mission agencies with fewer voices around the table [4]. While greater inclusion is desirable, diffusion of *responsibility* often bars cross-agency collaboration. For good or ill, both introduce factors that enhance wickedness. There is need for adaptive, networked, and participatory forms of planning, decision, and governance capable of supporting iterative reframing and prospective learning [9, 14].

The U.S. National Academy of Sciences has developed a useful formulation for how analysis may support operational planning when the science is not yet sufficiently dispositive or persuasive. 'Deliberation with analysis' envisions policy deliberation and formal analysis moving in parallel with repeated points of tangency [15]. Deliberators raise questions referred to the analysts who then provide preliminary results. The deliberators mull the findings, draw inferences, develop new questions, and indicate areas for greater detail. This begins the next iteration.

To address these needs, the field of decision making under deep uncertainty (DMDU) has developed concepts and tools better suited to CASs than those usually applied when probabilistic statements stand on firmer ground [16]. The philosophy of model use in the DMDU method of robust decision making (RDM) has proven capable of eliciting meaningful strategic and operational guidance in settings that have resisted treatment by traditional, prediction-based techniques [17].

Our paper reports a framework for putting together disparate elements: the theory of CASs combined with social science insight into wicked problems, scientific analysis in a decision-with-analysis process, narrative techniques for

conducting (and de-conflicting) deliberations, and the potential for DMDU to integrate them for defining and achieving specific policy outcomes. The second section describes our laboratory setting, housing problems in Metropolitan Monterrey in the state of Nuevo Leon. We then describe application of the Vision, Strategic Concepts, Assumptions, Robust Pathways (VSCARP) narrative-based participatory foresight method to engage a broadly based, heterogeneous group of participants in the design of a deliberation-with analysis process [18]. The fourth section describes the foundations and tailored modifications of the novel ECLIPSE (Endogenous City Landuse and Integrated Policy Experiment) agent-based urban model as the core engine within a RDM experimental design while the next shows preliminary findings designed to support the ongoing process of engagement. The final section provides thoughts on the process to date as well as the ambitions and prospects for further applications of the framework we describe.

2. The problem of housing in Metropolitan Monterrey

Metropolitan Monterrey (MM) is among Mexico's largest urban areas and drivers of national prosperity. Great demographic growth has fueled its economic dynamism. Providing housing to accommodate growth has become not just an acute problem but a wicked one as well. More than a purely local issue, housing is also an archetype of a general class of public policy problem. Resolving the local concerns could affect millions of people. Pioneering methods for addressing similar problems in different settings could have even greater influence.

The MM housing problem leads to ever more expansive development on the periphery causing secondary social, economic, and environmental ills. Several concerns and factors affect housing outcomes across MM.[†]

- *Regional economic development* is driven by global trade shifts from outside the region.
- The sixteen centers of government comprising MM have *no formal or informal regional planning body*, little to no integrated planning, and a history of political discord and regulatory mismatch.
- The political culture deems that adequate *housing and affordability are not a responsibility* of local government.
- *Policy priorities* across municipalities are ill-defined or mis-aligned. This is true within municipalities as well.
- There is lack of synchrony between *levels of federal, state, and local government* in policies touching on housing.
- *Regulations* are poorly aligned even across government offices within a single municipality. A large cause of dysfunction is not apathy but different actors and regulators following rules that have never been harmonized.
- *Incentives* in finance and construction lead to sprawl in new housing development. In core cities, buildable lots remain vacant or else the vertical intensity of subsequent construction is limited.
- There are *insufficient resources or planning* to provide utilities, transportation, and services to the periphery and when present those services often, ill-maintained, remain spotty and unreliable.
- *Long commute times* to employment and services arise from insufficiently integrated regional transportation.
- Insufficiently flexible financial instruments cause *housing abandonment*. In 2020, there were over 280,000 cases of abandoned houses in Nuevo Leon, in some cities amounting to above 20 percent of total housing stock [19].
- Social, cultural, and economic incentives in both demand and supply push toward single-family residence (SFR) housing. The rental share of housing in MM is low compared to other countries in North as well as South America.

MM housing is therefore typical of a wicked problem that involves many voices, interests, perspectives, and bodies of experience: problems look different to different people, are difficult to define, and connect many CASs composed of people and organizations acting independently. Policy outcomes are not easily predictable so profound uncertainties prevent deriving optimal strategies. Comprehensive solutions are difficult to frame so managing issues and consequences over time requires incremental approaches resulting from wide consultation and deliberation. Our project was to support local understanding and management of this CAS-based policy problem through a regional, comprehensive, policy-oriented group deliberative process to jointly determine what a widely held vision for housing could be in the year 2040 and what pathways might be available to attain it.

[†] Unless otherwise specified, all information in this section is based either on preliminary local interviews conducted across the community or on exchanges during the two-day Tecnológico de Monterrey (Tec) workshop held at Tec's San Pedro campus on 5-6 December 2024.

3. Participatory foresight to set the foundation

3.1. VSCARP and participatory foresight workshops

Standard analytical practice often begins with systems mapping followed by data acquisition, model development, and single-use analysis. For a CAS-based wicked problem, preparatory work should first be invested in problem framing and experimental design. The costs of not doing so might include insufficient engagement on the part of relevant actors or a model development effort that may not prove purposeful to inform decisions.

For this reason, the quantitative RDM analysis is preceded by activities to produce two outputs. The first is forensic analysis of the problem, its system, and the perspectives that stakeholders bring. The second is the process outcome of finding a common language, motivating a shared structure for thinking about actions and objectives dynamically across time, and recognizing commonalities that exist across interested parties even if they had previously been viewed as being in conflict. This is a crucial step in wicked problem re-framing.

Toward these ends, we conducted two workshops in the Monterrey area.[‡] The central concern was the question, "*How can Metropolitan Monterrey meet the need for affordable and quality housing for all its communities and inhabitants?*" The question was addressed in two parts:

- Is it possible to define elements of a jointly held *vision* for MM 2040 to meet housing needs, ensure economic and security benefits for residents, and improve coordination for the benefit of all involved?
- What *alternative pathways* for policies and strategies should be considered to achieve this vision by 2040 and how resilient might these be to trends, uncertainties, and future disruptions? In other words, how robust?

This breakdown is in keeping with the VSCARP intent to avoid consideration of strategy until after addressing the all-important question of what outcomes the strategies are intended to bring about [18, 20]. The goal was not to arrive at final conclusions but to begin a process of structured deliberations among authorities, communities, and stakeholders on a CAS-based wicked problem.

VSCARP limits difficulties associated with discussions of contentious issues. It seeks expression of viewpoints and ideas while channeling them into actionable steps. Direct confrontations are minimized through a combination of small and plenary sessions to explore elements for a group vision and jointly testing possible courses of action and their resilience properties. The intent (in this instance) is to conduct a laboratory to gain policy insights through interaction. VSCARP makes it possible to gather diverse perspectives for structured discussion and analysis, create a common language among diverse interests, and establish a common ground while recognizing key uncertainties. Paradoxically, strong group findings do emerge – often to the surprise of the participants.

3.2. Participatory workshop findings

The first of the product outcomes from VSCARP was a set of twelve elements to be included in a vision for MM [21]. The items that emerged were not surprising, but they provided two values: 1) a substantive starting point to begin the discussion of alternative policies and actions; and 2) a recognition that though generated by a highly heterogeneous group, starting from basic principles and working collaboratively led to broadly accepted results.

Participants also produced strategic alternatives for achieving the elements of the vision. Small groups were charged with generating simple, even simplistic, over-arching strategic concepts ("big ideas") from which more sophisticated strategies could emerge and be shared and tested. These were ultimately represented by five major strategic concepts:

1. **"*Efficient Monterrey*"** views the principal problem as being lack of effective and consistent means for framing, implementing, and enforcing policy and regulation.
2. **"*Well-financed Monterrey*"** sees the fundamental issue as marshaling financial resources and distributing in a manner to enhance incentives for adequate housing.
3. **"*Planned Monterrey*"** rests on the notion that better coordinated planning, information sharing, and transparency are keys to regional urban transformation.

[‡] We held the initial workshop on December 5 and 6, 2024, at Tecnológico de Monterrey's School of Government and Public Transformation, San Pedro Campus. A follow-on workshop was held at the same locale, July 2, 2025 to discuss findings from the first. Each workshop included 25-30 participants selected among local developers, municipal officials, business and finance leaders, civil society groups, and NGO representatives.

4. **"*Proximate Monterrey*"** views sprawl as the major problem so the way to access employment, transportation, and services is to reconstitute the region into a cluster of many economic and social activity centers.
5. **"*Reconceived Monterrey*"** focuses less on the material and more on the necessity for change in culture and attitude for a reconceptualization of the region and its housing choices.

That different groups see the core problem within this CAS-driven policy conundrum differently is well within the literature's understanding and definition of a wicked problem.

The second day of the initial workshop asked participants to determine for each strategic concept what explicit and implicit assumptions were included, which were key assumptions and how might they be vulnerable, what indicators should be monitored for early warning of possible assumption failure, and what ancillary actions could shore up the chances for success. Participants considered both hedging actions, those that might mitigate deleterious consequences of strategy failure, and shaping actions that could render the environment more conducive to a plan's unfolding. Table 1 shows the results from small and plenary group discussions of the "Efficient Monterrey" concept along these lines.

Table 1. Key assumptions, vulnerabilities, and hedging and shaping actions for the Efficient Monterrey strategic concept

Key assumptions	Vulnerabilities	Hedging & shaping actions

• Economic resources will exist
• Political will is sustainable
• Capacity for effective tech use exists
• Some central collaborative forum is needed
• Can define a unified vision
• Can withstand interests, counter to the shared vision
• Levels of government will collaborate and reconcile
• Incremental solutions can bring significant progress
	• Lack of leadership and political will
	• Divergent stakeholder interests
	• Priorities defined by political cycle
	• Differences among municipal governments
	• Differences among levels of government
	• General resistance to change by both officials and citizens
	• Technology reliance: availability, cost, training, security, and resistance to digitization
		• Hold recurring review meetings
		• Conduct audits on technology spending and deployment
		• Create entity for redistributing digital information to cities
		• Build strategic points for realigning the original plan
		• Take steps to enhance
		  • flexibility
		  • social participation
		Build balances against
		  • capture by interests
		  • measures detracting from systemic efficiency

Source: [21]

4. Modified ECLIPSE model and RDM experimental design

4.1. RDM analysis of problems with complex adaptive systems

RDM relaxes the predictive component found in most analytical approaches which often falters in the face of CASs. RDM also relies upon formal models and computer simulations but differs in the philosophy surrounding model use. Instead of ascertaining which assumptions might prove correct ("*What will happen?*"), models are employed in evaluating and characterizing alternative plans ("*What short-term actions would be consistent with long-term goals across many plausible futures?*") [22].

RDM requires problem framing since it largely proceeds backwards from the fundamental questions besetting decision makers [23]. Through an iterative Latin hypercube experimental design, the analysis generates cases based upon plan alternatives being competed across different specifications of unknowns. Runs are then examined for successful and unsuccessful outcomes. Algorithms are used to describe parsimoniously what variable values lead to systematic outcomes [24]. In contrast with the inductive logic approach to scenario formulation, RDM determines important scenarios analytically. Inferences are drawn by analysts and deliberators, new questions are raised, models are made more detailed in sub-modules that appear to make large differences in outcomes, and alternative courses of action are refined, hybridized, and subjected to renewed testing. After several cycles, decision makers can be presented with modified and stress-tested alternatives along with an understanding of how they may behave in different futures.

This research design has several implications. RDM becomes a tool for performing systematic, rigorous reasoning which more fully characterizes policy deliberation than does the deductive reasoning more familiar to analysts [4]. Because outcomes are almost always measured along several dimensions, optimization is no longer a viable approach. Instead, RDM recapitulates the satisficing approach to hedging positions so prevalent within decision organizations [25]. Unknowns are not characterized probabilistically but rather by exposing what effects different values may reveal

about choices and outcomes. And the model no longer holds such primacy as the focus for analytical endeavor. Instead of expending the bulk of time and resources perfecting a model before analysis begins, the model itself is a product of co-production through the length of the project as deliberation with analysis not only informs the policy deliberators but helps the analysts understand what instrumental use the model must support.

4.2. The ECLIPSE-M agent-based urban model

ECLIPSE. Agent-based models have been used extensively in the complexity science literature [26, 27]. The Endogenous City Landuse and Integrated Policy Sandbox Engine (ECLIPSE) simulates urban growth dynamics through interactions between individual households, owner-developer agents, and complex spatial spillover effects [28]. ECLIPSE adapts the Alonso-Muth-Mills (AMM) monocentric city model, a workhorse of urban economics in the tradition of [29] and extended by [30] to include externalities from public open space, to a dynamic agent-based framework. This format supports durable but reversible housing stock, vertical and horizontal features of development density, a completely mobile and open population, and the evolution of privately, socially, and publicly generated spatial amenities with full interaction effects. The structure enables stylized modeling of dynamic shocks, transitions, and path-dependent agglomeration effects among heterogenous households under alternative policy portfolios.

Space in the model is structured as a network of parcels $j \in J$ where connecting edges represent roadways. Each parcel has a design defined by three state variables: the fraction g occupied by open or green space versus building footprint $1 - g$, the density k of housing units within the footprint area, and the height expressed in number of floors z. Ordinances optionally constrain design parameters within subsets of parcels. In the current implementation, each parcel is owned by an absentee landlord $y \in Y$ who manages the design to maximize the parcel's net present value (NPV) given expected tenant demand, neighborhood characteristics, and the policies currently active. Current and prospective households $i \in I$ compete for available housing units based on their income, distance from work, unit size, and neighborhood characteristics. As an "open city" model, households are fully mobile within as well as into or out of the city.

Each simulation run begins with undeveloped space and zero population. In each period $t \in T$, the model state then evolves through a sequence of events. First, policy changes, projects, and other shocks are applied following a predefined event schedule or adaptive function. An arbitrary combination of policies with different timings can be applied such as income and property tax structures, incentive programs, and zoning rules or development ordinances. Projects might include public park developments, transportation system changes, and other infrastructure changes that affect land use and parcel connectivity. Then, an economic module updates to determine changes in household wages or other fiscal conditions that period. Initially, the distribution of household wages is such that no development is feasible. Wages then expand during a "burn-in" period to an equilibrium distribution until development patterns stabilize, after which experimental interventions are applied.

In the next phase, landlords update the expected NPV of the current and optimal alternative design taken from observed household willingness to pay (WTP), estimated as a weighted average of current parcel tenants and a sample of the city population. The WTP of a household for a dwelling on j takes into consideration the cost of commuting to the CBD where they work, the size of the dwelling, and positive or negative spillovers from the parcel and its surrounding neighborhood: nearby green or open space, congestion from commuting traffic, and social capital from social ties that form among neighbors.

A landlord redevelops if the change in NPV is positive net of demolition and construction costs which gradually rise with the volume of building. These agents have "myopic foresight" in the sense that they take current policy and neighborhood conditions as fixed though the use of information from current tenants provides localized feedback.

Prospective household agents are created for any new housing units. All households then sort into locations through an auction-like mechanism. First, the true WTP is calculated for each household across all locations. However, since each location can have k units, a household only needs to outbid the $k + 1$ willingness to pay, yielding a surplus utility from the difference. The market clears by serially matching the next household-location pair where that household can achieve no higher surplus utility and no other remaining household has a higher WTP. This matching continues until (i) the marginal household cannot reach a reservation utility level representing the next best alternative city, (ii) no housing units are available, or (iii) no households remain.

A social mixing stage optionally follows in which social ties form and decay among households within a neighborhood radius. The probability of forming a tie with another nearby household diminishes as the number of ties

for either party increases; this mimics cognitive and time constraints on socializing. Ties are more likely to atrophy as distance increases but are more likely to survive with age. Households gain utility through both direct (strong) and second degree (weak) ties, acting as both an endogenous mechanism for place attachment and potentially a draw to neighborhoods where familiar households have moved.

Finally, profits, taxes, and transfers are realized with taxes recycled as composite public services.

ECLIPSE-M. A completely abstract urban ABM would not engage participants grounded in MM local issues. A highly detailed representation would run the risk of failing to prove timely. A middle ground was to develop a design that showed recognizable fidelity to the major forces at play – for example by initially representing only four of sixteen municipalities. Granularity would be added based on guidance from the deliberations on where greater detail would gain greater insight.

Workshop outputs such as shown in Table 1 were placed within an XLRM framing (eXternal unknowns, policy Levers, causal Relationships, Measures) [31]. This creates an experimental design that defines the policy actors and brings them into the analysis, allows for non-linear reasoning (tradeoffs among the Ms are explored as much as different possible portfolios of Ls), and establishes a simple intellectual bookkeeping system as deliberation for analysis proceeds. Among the many model changes this motivated to create ECLIPSE-M, some major ones included:

- ECLIPSE had one city and central business district (CBD). ECLIPSE-M showed four such cities and CBDs.
- Participants highlighted both local and state governments, emphasizing efficient operations and municipal collaboration for more standardized planning regulations. Other key topics included housing development regulations, construction incentives, access to high-quality public services, quality public transportation, and urban sprawl causing longer commutes to recreation and commercial areas, increasing residents' time spent in traffic.
- We made two categories of metrics. Those affecting quality of life for households include commute times, financial burden (taxes, rent, and transport costs), access to public services, and amenities. Those affecting urban development and housing demand include housing abandonment, parcel occupancy, building height, urban sprawl, housing supply, and undeveloped parcel metrics.
- Government is not an agent. Its actions are implemented through effects on developers and households. The primary mechanism is tax collection: income tax from households, land tax from landlords, and an improvement tax collected when a parcel is redeveloped. These are then allocated to three defined areas: public services, amenities (at this stage only greenspace), and public transit. A defined share is allocated to public services; amenities and public transport have maintenance fees covered by the remainder. Any excess is returned to public services. Each municipality invests its collected revenue in public services and amenities. The portion dedicated to public transportation is passed to and managed by the state.
- Housing prices respond to rising demand for homes with strong public services, superior amenities, and CBD proximity.
- Local government affects housing by issuing construction permits, enforcing regulations, and providing development incentives. Permits can cause delays if the approval process is slow; regulations specify the permissible construction area, the number of floors, and the required green space for each project. Incentives are intended to stimulate housing development and might include payments for ecosystem services, loosening certain regulations, temporary tax exemptions or reductions, and expediting permit processing times.
- Concepts difficult to model are initially shown with multiplicative scalars with 0-1 range to determine whether strategies were robust to changes in value. If not, the scalars would be replaced with algorithms in future builds.
- Two exogenous parameters affect how well these government-related mechanisms work. Government efficiency affects how well the tax revenue is invested in the three areas described above: if low, then not all the tax revenue is spent and permit issuance is slowed.
- Unlike ECLIPSE, households can own developed parcels in ECLIPSE-M, a better fit with MM realities.
- A major factor in MM is INFONAVIT, Mexico's public mortgage lender and key driver of affordable housing development. INFONAVIT's regulations determine which housing qualifies for its loans, normally targeting units with low sale prices and compact footprints.
- Government cohesion determines how standardized regulations and priorities are across municipalities. Low cohesion may cause only some municipalities to prioritize the development of amenities and will also result in differing construction regulations.
- Unlike ECLIPSE, households can own developed parcels in ECLIPSE-M, a better fit with MM realities.

- A major factor in MM is INFONAVIT, Mexico's public mortgage lender and key driver of affordable housing development. INFONAVIT's regulations determine which housing qualifies for its loans, normally targeting units with low sale prices and compact footprints.

5. Preliminary findings for further participatory deliberations

The focus of this paper is on method and process. It presents a systematic framework for addressing normative and substantive issues in the analysis of policy problems involving CASs in a manner suited to real-world application. The intent is not to convey the details of a highly complex, multi-faceted analytical treatment. In this section, therefore, we present a few findings to illustrate the type of output that may be used to support deliberation with analysis.

To both evaluate the preliminary version of ECLIPSE-M and provide an entry level for local project participants, we designed three scenarios that showcase the implemented mechanisms. We named four municipalities in MM, but the data for these experiments only corresponded coarsely to their real-world equivalents at this stage. We assigned a probability that new citizens would arise in one of the four as well as conditional probabilities on where they would work. This allows the representation of origin-work asymmetries, a notorious aspect of MM's reality.

The Baseline scenario represents varying municipal government efficiency (spanning "Garcia" at 0.2 to "San Pedro" at 0.8), single-family housing regulations, and a lengthy permitting process.

The Efficient Monterrey-No Cohesion scenario is designed to show improvements in government efficiency and in zoning and construction-permit regulations. However, only two municipalities make these priorities. This allows us to explore what happens when there is no metropolitan plan leading to uneven conditions. Specifically, these municipalities are "Garcia" and "San Pedro" which are farther from the main work centers and can lead to migration towards the periphery.

Finally, the Efficient Monterrey scenario is a preliminary version of the scenario described in section 3.2, in which there is a metropolitan plan with standardized housing regulations across municipalities that have also become more flexible, permit processing times are low, and government efficiency is at an optimistic pitch.

Many types of output can be generated from the simulated outcomes; we select two for illustration. Figure 1 provides a static view of final rent and floor-height distributions across the spatial grid for the three scenarios. A red overlay indicates municipal boundaries. The municipalities with the highest spawn probability and probability of employment (not shown) are "Guadalupe" and "Monterrey," located at the central-bottom and left quadrants of the grid, respectively, while "San Pedro" and "García" with lower probabilities are in the central-top and right quadrants. In all three scenario simulations, the first 30 steps are run under baseline conditions. The two policy scenarios then transition to their intended parameters using a ramp function between steps thirty and forty. After step forty, the parameters reach their target levels. The simulations continue until step sixty.

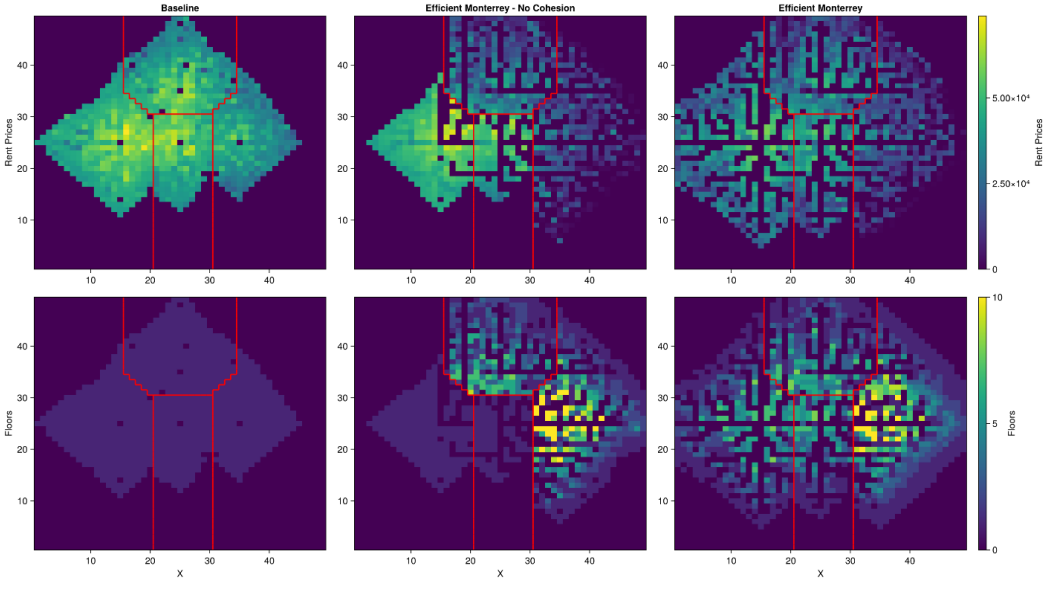

Fig. 1. Final-period patterns of rent burden and floor-height shifts in Metropolitan Monterrey under three scenarios

Note: The columns represent the three scenarios: Baseline, Efficient Monterrey-No Cohesion, Efficient Monterrey, respectively from left to right. The first row shows final outcomes for rental prices across the municipal grid. The second row shows outcomes for building heights in number of floors. The red lines show municipal boundaries.

The baseline scenario reflects the SFR constraint with development concentrated around the CBDs. The low capacity induced by zoning regulations in this scenario leads to a considerable increase in rent prices. Efficient Monterrey-No Cohesion illustrates how tighter zoning regulations reduce the development capacity of "Guadalupe" and "Monterrey," slowing their growth. Meanwhile, "San Pedro" and "García" benefit from more flexible zoning regulations, and "García" additionally receives a 20 percent reduction in land tax, a 50 percent reduction in redevelopment tax, and a tax exemption for new constructions. These incentives increase municipalities' capacity and drive migration despite greater distance from the most sought-after CBDs. Greater housing availability drives prices down in "San Pedro" and "García," while prices in "Monterrey" and "Guadalupe" remain considerably higher. Finally, the "Efficient Monterrey" scenario demonstrates how development across all municipalities grows substantially due to tax incentives in "García" and more flexible zoning regulations driving down rent prices across the entire metropolitan area.

The participatory foresight described in Section 3 encourages developing a group ability to think across time. The ABM formalism used in ECLIPSE-M supports this with corresponding analysis. Figure 2 presents an analysis of mean rent, mean commute time, and mean quality of life across municipalities for the three scenarios.

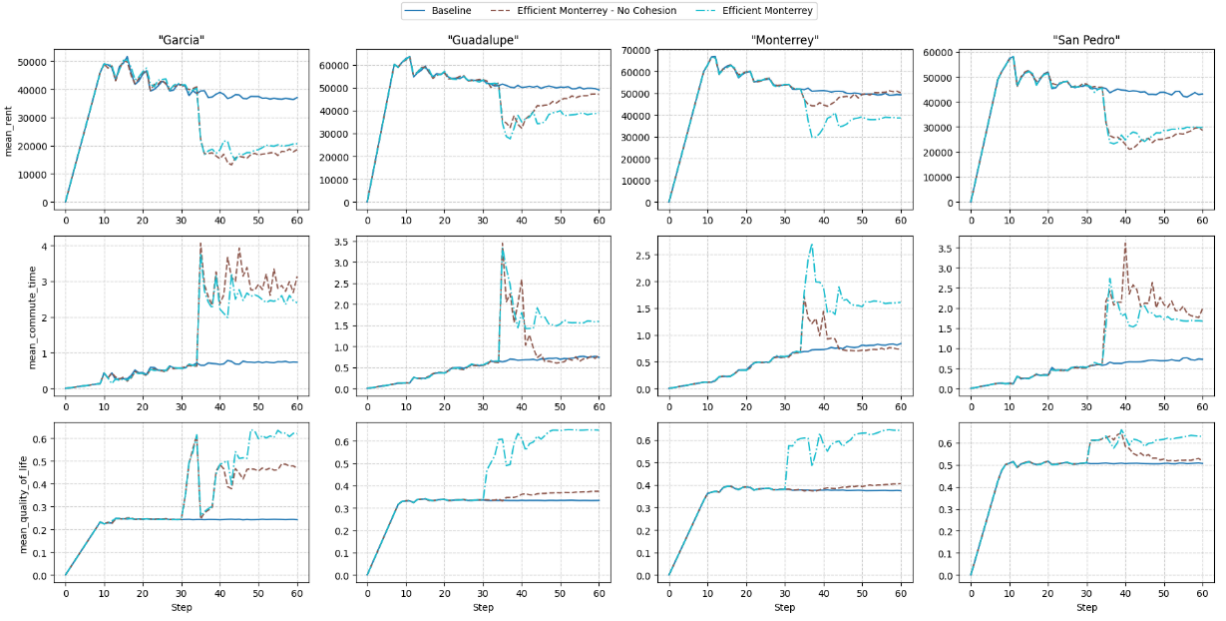

Fig. 2. Dynamic paths for three scenarios, by municipality, of mean rent, mean commute time and mean quality of life

Note: The columns represent results for the four municipalities, "Garcia", "Guadalupe", "Monterrey", "San Pedro", respectively from left to right. The first row shows dynamic changes over time in mean rents. The second row shows outcomes for mean commute times. The bottom row shows outcomes for mean quality of life, a concatenation of commute time, financial burden (taxes, rent, and transport costs), and access to public services and amenities outcomes.

Across all municipalities, the three scenarios exhibit a similar initial trajectory, characterized by rapidly increasing rents as demand grows, followed by a structural break around the mid-simulation period. Subsequently, the baseline scenario maintains relatively high rent levels while both policy scenarios result in substantial rent reductions, particularly in peripheral municipalities such as "García" and "Guadalupe". The "Efficient Monterrey" scenario produces the largest and most sustained decreases consistent with higher development capacity and more

uniform government efficiency. In contrast, the "No Cohesion" scenario demonstrates more uneven adjustments across municipalities.

These changes in housing costs are accompanied by sharp increases in commute times under both policy scenarios reflecting spatial reallocation and expansion effects. The increase is most pronounced in the short term after which commute times gradually stabilize but remain above baseline levels. The "Efficient Monterrey" scenario demonstrates slightly better stabilization indicating improved spatial efficiency compared to the uncoordinated scenario.

Despite longer commutes, both policy scenarios yield improvements in quality of life relative to the baseline. The QoL index aggregates access to public transport, proximity to parks, commute time, financial burden (housing and transport costs relative to income), access to public services, and residual consumption. Each component is normalized and the final index is a weighted average ensuring comparability across scenarios. Improvements in affordability and service provision outweigh the negative effects of longer commutes, particularly under the coordinated "Efficient Monterrey" scenario, which delivers the largest and most consistent gains. In contrast, the "No Cohesion" scenario exhibits greater volatility and weaker improvements in some municipalities, underscoring the importance of coordinated policy design for achieving balanced urban outcomes.

At this stage of development, ECLIPSE-M clearly contains stylized characteristics modeled at low resolution. Several variables, for example, appear solely as 0-1 scalars. Though parsimonious, the approach is also purposeful in several respects. Working within the non-predictive framework of RDM analysis, the question is less to determine what outcomes may be expected than to enquire, "what would you need to believe will be true to advocate for different policy alternatives?" Working within the deliberation-with-analysis process, once given the prompt the participants can determine what might enhance characteristics such as government efficiency or regional coherence. And finally, it is precisely this deliberative process that will inform the modelers what aspects of the problem would need to be resolved at higher resolution of detail for subsequent rounds of analysis. This approach allows early examination as well as engagement that will educate both the analysts and the participants in a virtuous cycle of joint exploration.

6. Conclusions and prospects

This paper suggests means for moving from the science of complexity toward a technology of complexity. It does not present a final resolution to the MM housing problem. Wicked problems are rarely resolved but are instead managed over time. The intent instead was to provide a template for considering how to bring computer tools and analytical means to bear on CAS-based wicked problems. Technical tools alone are insufficient because the epistemic and normative aspects of the wicked problem are key. Cross-method protocols need to be developed and tested.

Although this deliberation with analysis is still underway, the approach to policy treatment of a CAS-based wicked problem has shown its worth sufficiently to warrant greater exposure. Designed to pair participatory foresight with DMDU analysis for simultaneously addressing both the normative and technical aspects of a wicked problem, the process has to date gained notable local engagement. An informal "shadow" process is being constructed not to usurp the roles and prerogatives of formal institutions, but rather to provide a more effective interface among affected parties. In part, this provides a platform for regional engagement that presently does not exist. The ultimate effect will be determined by the nature of substantive outcomes from future deliberations. The intended outputs are designed to illuminate available choices in a sharable and testable form, examine the possible consequence of each across different futures, and determine which among many possible factors should receive most scrutiny in making policy choices.

But other factors will also determine ultimate effect. The work in this paper is experimental in two senses. First, it explores approaches that weave together a suite of methods to address key challenges raised by policy problems rooted in CAS phenomena. Second, it does so in a regional and national setting characterized by long standing issues of low social trust [32] and a history of problematic interactions between bureaucracies and the public they are intended to serve [33]. While these are certainly potential challenges, they also provide the prospect that the approach laid out in this paper could prove to be even more valuable if it can break through traditional patterns that inhibit other approaches to resolving similar seemingly intractable problems. This will only become clear after we can also view the experience of similar trials conducted in other places and treating other problems. All the more reason to share this project's experience at an early stage.

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