Dynamic Microsimulation of Heterogeneous Spatial Markets

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ABSTRACT

A system for dynamic microsimulation of urban spatial markets is described, where individual economic units (primarily business establishments and households) are simulated. Long term relationships that lead to regular travel are simulated (e.g. workplace/employer, normal shopping locations) together with casual relationships and transactions causing a typical day's travel. The diversity of trades and interactions is represented by forming "parcels" of goods, services, labour or other (non-market) interactions. Each parcel is described by a number of attributes, coded mathematically as integer or real numbers. The attributes represent characteristics of the parcel, including a category, monetary value, size and quality. Certain attributes can correspond to attributes measured in observed data; other numerical attributes can be included as representative of unmeasured diversity. Economic units regularly make "offers", which are proposals to exchange (e.g. to purchase or sell) a particular parcel at a particular location. Examples of such offers include product descriptions in catalogues, help wanted ads, television commercials and social invitations between friends and family. An exchange occurs when such an offer is accepted by another economic unit.

In the proposed framework, economic units use a rational expectation and information search process to develop a set of interactions desired, expected or needed based on their lifestyle. This produces a set of "expected parcels", which are specific transaction expectations that the economic unit has in mind. Each of these leads to an explicit search for a suitable transaction. For each such expected parcel the economic unit searches for a set of similar offers already proposed at various locations. It then makes a choice to accept one of those similar parcels at a location, or to instead publish an offer of its own based on the "expected parcel". There is a continuous supply of offers and the quantity, type and spatial arrangement of outstanding offers at any time influences the choice of whether to accept an existing offer or to publish a new offer.

This process is simulated in four stages for each economic unit: 1) the creation of expected parcels by selecting attributes from distributions, with the parameters of the distributions dependent on

lifestyle needs, rational expectations and information searches; 2) a search process that establishes a set of offers to consider for each such expected parcel; 3) for each expected parcel, a behavioural choice model between the offers considered and the additional alternative of publishing a corresponding offer of ones own, and 4) the updating of lifestyle and expectations based the economic unit's ability to match its wants and needs through accepting offers or having offers accepted.

Each of the above components can be operationalised using simple models. Lifestyle and expectations (1) can be described as an explicit list of expected parcels, randomly generated based on the economic unit's unique characteristics. The search process (2) can be an equal-probability random selection between all offers in the same category as the expected parcel. For long term relationships the existing situation is also included as one of the alternatives. The choice model (3) can be a nested logit model based on random utility theory. The representative utility of each considered offer can be a linear function of the differences between its attributes and the expected parcel's attributes, and the perceived travel conditions to the offer's location. For long term relationships the existing situation's representative utility can have an additional constant representing the tendency to avoid change. The utility of making an offer can be a constant dependent on the category of transaction. The updating of expectations (4) can be an adjustment of price and quantity expectations for each expected parcel based on the number and utility of the past transactions involving the expected parcel.

The framework moves through time as a discrete event simulation. Components (1) and (4) can be considered in longer (e.g. one-year) time steps, while components (2) and (3) are scheduled for each expected parcel at a specific time within the longer time period.

The framework represents the purposes for all trips in an urban area, and hence all travel, and the supply and demand for all goods, services and social interactions. Thus the framework captures the *raison d'être* of cities -- to provide a variety of accessible spatial interaction possibilities between complementary actors.

The framework is envisioned as the basis for practical simulation tools for transportation and urban planning policy analysis and government decision making. In such a role, the simulation would calculate travel conditions endogenously based on a transportation network simulation of the route and travel mode choices for each simulated exchange. The foundation of the framework on economic interactions is in contrast with "activity based" transportation planning models, which focus on the activities performed by people over the course of a day without a strong representation of the interactions that occur during those activities. The framework is thus an appropriate tool for economic analysis of transportation policy based on the benefits that occur to firms and households when transportation systems support access to diverse transaction opportunities.

The proposed model can represent the differing effect of policy on economic units or trades categorised by any of the attributes used to represent them. Local microlevel interactions (e.g.

pedestrian movements and symbiotic relationships between nearby firms) can be represented, as there is no need for zones or zonal averages.

The framework was designed with the intention that it would support a longer-term urban economic model that has a realistic representation of the formation of spatial clusters of complementary activities in urban areas. Such clusters are often highly specialised and spatially very small, with substantial pedestrian movement between the economic units in the cluster. The framework has been designed to allow unlimited spatial detail (without the Order n^2 performance degradation that occurs in zone-pair representations of interactions) and arbitrary diversity in the representation of the unique characteristics of the actors and their desired interactions. Thus the framework can represent the advantages of such micro-level clustering based on the unique characteristics and needs of economic units.

This paper describes the framework and compares the framework with other frameworks to identify its advantages and disadvantages. Issues in applying the framework to different types of firms and households and different categories of transactions are discussed. The paper concludes with recommendations for further research to apply the framework as a calibrated and operational model of a specific urban spatial economy.

KEYWORDS

spatial market simulation, agent based urban economics, urban diversity, transportation planning

Introduction

The study of spatial economic systems is characterised by the consideration of transport costs and location in economic transactions. Individual actors, or agents, exchange goods or services with one another, and those exchanges are identified by the location of exchange, as well as by the unique characteristics of the good or service and the unique characteristics of the two parties making the exchange. In many cases, the location is the most important aspect of the transaction: two parties are brought together and decide to interact because they are conveniently located near one another.

When space and location are important, the range of transactions is influenced by the parties' desires to limit their amount of travel. This allows prices to vary by location. This has been represented in aggregate economic models by dividing space into categories, or "zones", and establishing a market clearing price in each zone for each category of good or service (each "commodity") in each zone.

Space and location are particularly important in transportation planning and in urban economics. Thus these disciplines have traditionally been pushing the boundaries of this representation, dividing space and categories of goods and services into smaller and smaller units of representation. The number of different markets increases with the product of all these categorization types, leading to a categorization system with numbers of categories approaching, or exceeding, the number of actual transactions that may occur on a given day. This has led to a realization that the aggregate, market clearing, categorization approach of representing spatial markets is not necessarily a simplification of reality. It may be more computationally efficient, and more behaviourally accurate, to represent each of the interactions that occur in a region or city individually.

This paper discusses the more traditional aggregate representation of urban spatial markets, illustrating the important features that need to be included in any microsimulation of those markets while also describing the limitations and unrealism of the aggregate representation. Then, the framework is described in detail. Finally, future research issues are described, focusing on integrating the spatial market simulation system into a larger spatial dynamics forecasting tool.

Aggregate representation of spatial markets

Spatial markets have been represented in aggregate equilibrium frameworks with traditonal economic assumptions regarding homogeneity of goods or services and perfect information. Under such traditional assumptions, a purchaser in a given location will only purchase from a market in a location if the sum of the market price and transport costs is better than for any other market. Similarly, a seller will only sell to a given market if the price less transport costs is better than for any other market. The Koopmans-Beckmann model (1957) is an early example of such a model.

This type of model suffers from the usual limitations of uniform-actor perfect-information models: unrealistic boundaries between different types of behaviour. A more realistic approach, with smoother and more stable mathematics, was originally proposed by Lowry (1964). In Lowry's model a probabilistic procedure is used to allocate the dependencies of activity in one zone to all zones, with closer zones receiving a larger share of the relationships. Lowry's model does not represent the dependencies as economic transactions involving goods or services: rather the relationships between actors are modelled directly, with three types of actors: basic employment, secondary employment, and households. There is no representation of prices.

A practical and useful extension of Lowry's model is embodied in the "Martin Centre" type of model, such as MEPLAN models or Tranus models (Hunt and Simmonds, 1992). In this type of model, the relationships between actors are more diverse, with a Social Accounting matrix describing how each sector of the economy (including households and their labour) relates to each other sector of the economy. Prices are established for each sector's output commodity in each zone. The consumption of the production of each sector in each zone is allocated to other zones using a logit model. This provides a behavioural representation of the choice of customer, based on discrete choice theory with the attractiveness of each zone subject to random variation. The deterministic part of the attractiveness is calculated based on modelled values, but a random component is added using a Weibul distribution. The size of the random component controls the amount of dispersion in the location of activities and interactions. The theory of random variation isn't carried through the framework, however, since increased variation in commodities does not lead to increased efficiency/utility in the actors using the commodities.

The distributions are always integrated, giving probabilities, and the law of large numbers is assumed to hold to allocate shares based on the probabilities.

A review of the MEPLAN modelling framework from an urban economics perspective is available in Abraham, 1998.

A more comprehensive extension of the Martin Centre model has been developed by (Hunt and Abraham, 2001). In Hunt's representation, classifications of goods, services, labour, capital or land are called "commodities", and a price is established for each commodity in each zone as an "exchange price". A market for a commodity in a zone is called an "exchange". To acquire a commodity in a zone, a purchaser makes a discrete choice from among exchanges, only one of which is in the same zone as the purchaser. The discrete choice is made using random utility theory (as in the Martin Centre models), with random variation in characteristics, perceptions and preferences causing agents to choose exchange markets that appear sub-optimal when the modelled prices and transport costs are examined. An important advantage of the Hunt model is that the random utility theory is carried through the model, with the expected maximum utility ("composite utility") of the choice between exchanges being a measure of the overall attractiveness of acquiring a commodity in a zone. This composite utility does increase as variation in commodities increases, unlike in the Martin Centre models.

To disseminate a commodity from a zone, the commodity must be shipped to an exchange where it can be acquired by a purchaser. The quantity of a commodities produced in a zone is allocated to exchange zones, representing the sellers' discrete choice from among exchanges. This discrete choice is also represented using a logit model based on random utility theory. The composite utility of this model is the overall attractiveness of producing a commodity in a zone for sale.

Hunt's generalization does not represent individual buyers or sellers, and does not represent individual commodities. It represents commodities as aggregate quantities and represents buyers and sellers as quantities of activity in zones. The activity types have "production functions" and "consumption functions" which describe the quantities of different commodities bought or sold. The region-wide quantity of each type of activity is allocated to zones using another logit model, with the attractiveness of each zone being a function of the composite utilities of acquiring or disseminating each commodity in or from that zone.

Given a set of prices for each commodity in each exchange zone, Hunt's generalization allocates activity to zones, and purchases and sales to exchanges. To achieve an equilibrium, Hunt's generalization adjusts the price of each commodity type in each exchange zone iteratively, and reallocates activities and quantities, until each market in each exchange is cleared.

Hunt's generalization of the Martin Centre model has a number of features that are important and should be preserved in spatial modelling work:

- goods and services transactions are unique, and an increased variety or availability of available transactions should increase the overall attractiveness for both buyers and sellers.

- there should be a preference for shorter shipments – for exchanging goods or services at nearer zones.
- prices should be allowed to vary across a region, with prices tending to act to match supply to demand in any one place
- Actors exchange "commodities" with other actors. For spatial economic modelling, the most critical aspect of an actor is the description of the commodities needed (the actor's "consumption function") and the commodities produced for sale (the actor's "production function")

The Martin Centre model (and Hunt's generalization of it) use of the "law of large numbers", where shares are assumed to be equal to probabilities. Thus they are ideally suited for modelling a large economy, with limited categorization into zones, activity types or commodity types. As the number of zones, categories of activities and categories of commodities grows the size of each cross-categorization becomes quite small. The number of elements in commodity flow matrices can easily become much larger than the number of transactions that typically occur in a region in a day. The law of large numbers becomes inappropriate. A statistical simulation becomes more appropriate.

Statistical simulation has another important advantage: the simulation itself serves as a Monte-Carlo integration of the various assumed distributions. In statistical simulation it is not critically important to restrict the model to have random variables with functional forms leading to "closed form" integrals. Microsimulation modelling allows the assumption of arbitrary distributions and correlations, allowing distributions to be based on behavioural theory and processes rather than on considerations of whether the integration is "closed form".

It is worth noting, however, that estimating parameters for any simulation is much easier when the underlying mathematical model leads to closed-form calculation of probabilities. A micro-simulation model can also take advantage of newer developments in closed-form models (Koppelman and Sethi, 2000), to avoid the simple logit formulations in the Hunt model or the Martin Centre model.

A disaggregate representation of spatial markets

This paper describes an approach for disaggregate simulation of heterogeneous spatial markets. The focus of the model design is on:

- representing the heterogeneity in transactions
- representing the heterogeneity in the two agents involved in any transaction
- avoiding any need to divide space into "zones"

- directly representing supply and demand for categories of goods and services by representing the willingness to be the supplier or purchaser in a transaction

Parcel heterogeneity

"Parcel" is a term used to define a bundle of goods or services that can be exchanged between two actors. It could be as elemental as a manufactured good offered for retail sale, or it could be slightly more complex, such as a shopping cart full of groceries. The defining nature of a parcel is that it is involved in a single transaction between two agents.

To distinguish parcels from one another, parcels have attributes which can be integer numbers or real numbers. An important integer attribute will be the "commodity category" from standard industrial classification codes used by government agencies. An important real number attribute will be the size, or quantity, of the parcel. For many service categories the duration will be critical (labour, for instance, is usually purchased as a permanent job with an indefinite duration, but can also be purchased as casual day-to-day labour.) Other attributes could be based on other observed data. To represent full heterogeneity, at least one real number attribute will be sampled at random from a distribution and not based on observed data.

Parcels do not have to be commercial goods or services. An interaction between close friends can be an exchange of a "parcel" of social value. The framework is meant to be comprehensive and useful for transportation planning, so a parcel should be defined for each trip made by people or shipments of goods or services in a region.

Offers

"Offer" is a term used to define a proposal to exchange a particular parcel at a particular location. An offer is a parcel, together with a location, a price, and an offerer. Examples of offers include product descriptions in catalogues, help wanted ads, television commercials and products on shelves at retail establishments. Non-market offers include social invitations between friends and family (to exchange a "parcel" of friendship or kinship).

In reality transactions may occur without an offer having been made. Two parties may simultaneously decide to exchange something without one of them first making an offer. For computer simulation, however, it is essential to "build up" the transaction by first having one party make an offer, and then having another party accept the offer.

Thus, at any one time, there must be a supply of outstanding offers. These offers are stored in a data structure, and simulation moves through time and through agents, with agents making offers (and adding them to the pool of offers) and/or accepting offers (and removing them from the pool of offers.)

Economic Units

Economic Units are the agents that make or accept offers. In the prototype framework an Economic Unit is either a household or a business establishment. Households or business establishments have locations. For households, their location is their home.

Firms, individuals and employees could also, presumably, make or accept offers. This would require considering the complex relationship between households and the various household members, and between firms and their establishments and their employees. The initial focus is on households and establishments, as their location in space is clear and they usually function as single units since their members (household members or employees) are willing to share parcels or cooperate to buy or sell parcels.

The focus in operationalizing the model framework is on representing how Economic Units make offers or accept offers.

Expected Parcels

To ensure that each agent is unique and to represent the differences between different types of firms and households, an Economic Unit first begins with a list of expected parcels. The expected parcels are a list of what the Economic Unit would like to achieve in a simulation period. A professional household, for instance, may wish to sell a certain quantity of labour by exchanging a parcel of a full-time job with an employer, and will also wish to purchase a parcel of groceries. A food service establishment, on the other hand, will have sales targets defining the quantity and type of meals it wishes to sell, and will have a list of "job positions" that it wishes to fill by purchasing labour. The mechanism for creating the list of expected parcels may be critical to the detailed operation of a realistic simulation; but for describing the framework it is only critical that a list of expected parcels is generated at random for each Economic Unit based on the characteristics of the Economic Unit. Initially, the simulation produces a random set of Expected Parcels based on production functions and consumption functions similar to the functional forms used for aggregate activity categories in Hunt's generalization of the Martin Centre model.

The Expected Parcel has a location, although the location is the *most advantageous* location for the Economic Unit to acquire or divest the parcel, and not the *expected* location. Normally this is the same as the Economic Unit's location. The Expected Parcel also has a price. The Expected Parcel is, essentially, a "potential offer" – the Economic Unit will, at various times, make a decision as to whether to make an offer to acquire (or an offer to divest) an Expected Parcel.

Offers to Consider

For each expected parcel, an economic unit eventually makes a choice. Before making the choice, a set of outstanding offers that others have made is identified for further consideration. If the Expected Parcel involves divesting a certain amount of a commodity category, then the set will consist of offers to acquire amounts of the same commodity category. Similarly, if the Expected

Parcel involves acquiring a certain amount of a category category, then the set will consist of offers to divest parcels of the category.

The identification of this set is to address a concern with the traditional logit model, as applied in the Martin Centre models and the Hunt model. The logit model is based on an assumption that the decision maker evaluates the utility of every possible alternative. When the number of alternatives is large this is an unrealistic assumption. Potential problems from applying logit models to large numbers of alternatives include:

- Unrealistic expected utility for the chosen alternative. In the logit model the utility of the alternatives has a random component that varies according to a distribution with infinite tails; and when there are a large number of alternatives one of them will be quite attractive primarily because of the random component. The logit model assumes that the decision maker can find this most attractive alternative and chose it. In reality most people do not make an optimal choice, because of imperfect information and the costs of searching.

- The necessary computing resources can be substantial. For complex choice sets involving multiple dimensions the number of possibilities can easily overwhelm any computing resources. Sequential approaches (using conditional choice models) can help somewhat, but are still subject to infinite expansion in required computing resources to calculate the expected utilities of the lower level choices.

These two problems are really two symptoms of the same problem: individuals do not consider every alternative in large choice sets, and to consider every alternative in a computer simulation is both unrealistic and computationally excessive.

Thus, an initial "search process" is used to establish a set of alternatives for further consideration. The representation of the search process may be an essential part of establishing a realistic overall simulation. It is likely that several process will be represented:

- imitation, where agents examine the actions of other agents similar to them (their peers or competitors), and consider similar actions for themselves,

- spatial search, where opportunities are identified near currently frequented locations, or a "search tour" is conducted from such locations,

- repeated behaviour, where actions performed by an Economic Unit at one time period are also considered in future time periods, and

- refinement, where after one alternative is identified small changes to it are also considered.

Initially, the only one of these four search processes represented is repeated behaviour. The others are replaced by a simple placeholder – a random selection of a certain number of additional offers from the full list of offers of the appropriate commodity category. This simplification is appropriate in the initial simulation to prove the basic framework. The framework can be made more realistic in future work by improving the behavioural processes by which offers-to-consider are discovered.

Probabilistic Choice Simulation

A transaction only occurs when an offer is made by one Economic Unit and accepted by another Economic Unit. Thus Economic Units must be able to both make offers and accept other offers.

Changes in the number, price, quality or size of outstanding offers should be an indication of changing market conditions. For instance, vacancy rates (offers to lease space) are an important indication of the real estate market. Unemployment rates (offers to sell labour) and "help wanted indices" (offers to buy labour) are important indications of the employment market. Making a public offer involves a certain amount of cost and uncertainty – cost of publishing or advertising the offer, and uncertainty as to whether the offer will be accepted by some other party. Thus, for both purchasers and sellers, it is more appealing, all else being equal, to accept an already published offer. For instance, if a job seeker sees a "help wanted" ad that seems suitable, they will accept that job rather than going through the trouble of creating and distributing a resume. If a firm has already been approached by an employment candidate that seems ideal, they will be unwilling to bother advertising in the help wanted section.

Thus each Economic Unit, for each Expected Parcel, makes the choice of whether to accept an offer made by another economic unit, or, alternatively, whether to publish an offer of its own. This is represented with a nested logit model:

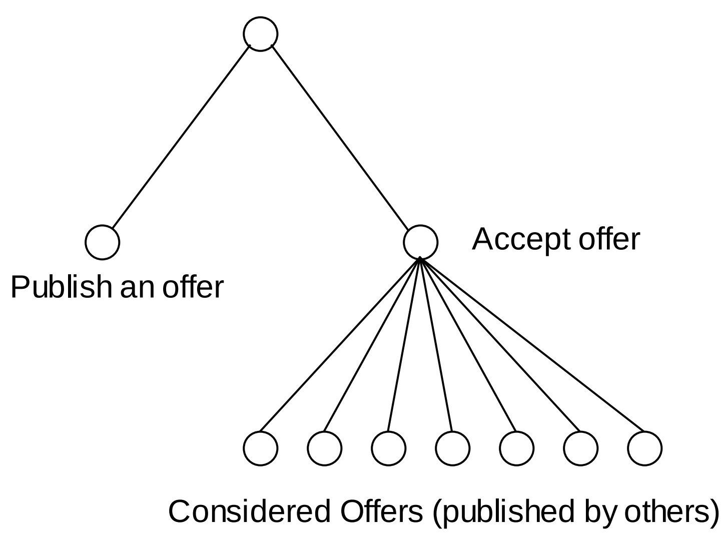

Figure 1: Choice to be made for each Expected Parcel for each Economic Unit

The top level choice is the choice of whether to accept an existing offer or to publish an offer of one's own. The second level choice is the choice of an offer to accept, conditional on the choice being made to accept an offer. The utility of accepting an offer is the maximum utility of any of the individual Considered Offers.

The nested logit formulation has two random components in the utility function, one associated with the top level of the nesting structure and one associated with the bottom level of the nesting structure. Thus the attractiveness of each considered offer is

$$U_{co} = V_{co} + \varepsilon_{co} + \varepsilon_{accept}$$

where ε_{co} is the random component associated with the individual offer under consideration,
ε_{accept} is the random component associated with the choice to accept one of the Considered Offers, and
V_{co} is the non-random component of the utility of the Considered Offer, calculated as described below.

The attractivenes of making an offer is

$$U_{mo} = V_{mo} + \varepsilon_{mo}$$

where ε_{mo} is the random component of the utility of making an offer, which has the same distribution as ε_{accept}
V_{mo} is the non random component of the utility of making an offer, described below.

The error components can be sampled directly from the associated Wiebul distributions. In aggregate application of logit models it is traditional for the utility of the "Accept Offer" alternative (the right branch at the top of the tree in Figure 1) to be calculated by "integrating out" the random components of the individual Considered Offers, so that the expected maximum utility of the lower branches is used:

$$U_{accept} = V_{accept} + \varepsilon_{accept} = \left(\frac{1}{\lambda} \ln \sum_{co} e^{\lambda V_{co}} \right) + \varepsilon_{accept}$$

where λ is a parameter inversely related to the variation in the distribution for the various ε_{co}, and
V_{accept} is the expected maximum utility of the lower branches.

In this microsimulation model, where an individual alternative is selected at random, there is no need to calculate the expected maximum utility of a group of alternatives: the *actual* maximum utility that is simulated is a richer representation of what occurs than the *expected* maximum utility.

Non random component of utilities of alternatives

Each choice made by an Economic Unit is a choice that relates to an Expected Parcel. Thus, for each offer considered, the offered parcel can be compared to the expected parcel. This comparison establishes the non-random component of the utility value for the offered parcel.

The comparison compares the set of integer and real attributes used to describe both the Expected Parcel and the offered parcel. For some attributes, such as price, the value for the expected parcel is not important as the value for the offered parcel has a unidirectional influence on its attractiveness. Other attributes might only be descriptive and not imply any value or quality, in which case the value of the attribute for the offered parcel is compared with the value of the attribute for the Expected Parcel to measure the difference between what was wanted and what is being offered. The absolute value or square of the difference would negatively impact the utility. Finally, the expected travel disutility to and/or from the location of the offer impacts the attractiveness of the offer. Thus, the utility of any offer is given by

$$V_{co} = \sum_i f_i\left(X_i^{CO}, X_i^{EP}\right) - TC_{L_{CO},L_{EP}}$$

where X_i^{CO} is the value for attribute *i* for the Considered Offer,

X_i^{EP} is the value for attribute *i* for the Expected Parcel, and

$f_i()$ is a functional form for evaluating the attribute *i* of the Considered Offer and comparing it, if necessary, to the attribute of the Expected Parcel.

$TC_{X,Y}$ is a measure of the disutility of travelling between location *X* and location *Y*

L_{CO} is the location of the Considered Offer

L_{EP} is the location of the Expected Parcel, which is the same location as the "home" of the Economic Unit.

The non-random component of the utility of publishing an offer rather than accepting an offer is based on the attributes of the Expected Offer, plus a constant that is fixed for each class of commodity for either acquiring (e.g. buying) or divesting (e.g. selling):

$$V_{mo} = \sum_i g_i\left(X_i^{EP}\right) + K_{CC}^{D}$$

where $g_i()$ is a functional form for evaluating the attribute *i* of the Expected Parcel.

K_{CC}^{D} is the constant associated with commodity class *CC* and direction *D*

D is either "acquiring" or "divesting".

The functions $f_i()$ and $g_i()$ control how the attribute *i* influence the choice. In the current work there are only two types of attributes. One type has a unidirectional influence on utility, so:

$$f_i\left(X_1, X_2\right) = g_i\left(X_1\right) = \theta_i \cdot X_1$$

where θ is a parameter controlling how increasing values of the attribute increases the value of the utility.

The other type only measures the difference between what is expected and what can be obtained through accepting an offer, so:

$$f_i(X_1, X_2) = \theta_i \cdot (X_1 - X_2)^2$$
$$g_i(X_1) = 0$$

K_{CC}^{D} is used to control the relative amounts of offers of different directions for a commodity. Some commodities, such as retail goods, have a large number of "sell" offers in the real world but very few buy offers. $K_{retail}^{divesting}$ will be positive and large, since retail establishments continually offer goods for sale but are rarely willing to customize a good specifically for the needs of one customer; and $K_{retail}^{acquiring}$ will be negative and large, since households mostly purchase goods "off the shelf".

If an economic unit decides to publish an offer rather than accept an offer, the offer is published at the Expected Parcels location (which is usually the home of the Economic Unit) and price. The published offer will normally be open until the Economic Unit again considers the same Expected Parcel, at which point it may be re-offered with updated expectations.

Updating of Expected Parcels based on experience

To achieve a dynamic trend towards equilibrium the Expected Parcels are updated based on the ability to enter into a transaction to acquire or divest a parcel similar to the expectations. If, over time, an Economic Unit continually chooses to accept an offer rather than make an offer when considering an Expected Parcel, then the price (or other attributes) of the Expected Parcel will be adjusted to be more optimistic (price would adjusted down for buyers of a commodity, and adjusted up for sellers.) Similarly, if an Economic Unit decides to make an offer rather than accept an offer, and the Economic Unit's offer is quickly accepted by another Economic Unit, then the Expected Parcel will be adjusted to be more optimistic.

On the other hand, if an offer is made and the offer is not accepted, or is only accepted after some delay, then the Economic Unit will adjust its Expected Parcel to be more pessimistic.

Thus, if there are a large number of similar offers outstanding and not many takers, then the Economic Units who made those offers will begin to compete with each other by adjusting the price or other attributes. On the other hand, if an offer is in high demand it will be accepted quickly, and the offerer will realize that there is potential to benefit from their unique position in the future.

As the price or attributes of expected parcels is adjusted, the size of the Expected Parcel may also be adjusted, the Economic Unit may add another (similar) Expected Parcel to it's list of Expected Parcels, or the Expected Parcel may be dropped for future consideration. This allows for aggregate changes in the supply and demand for each commodity. The number of outstanding parcels on the supply side and on the demand side are, together, an indication of the shortage and/or surplus of the commodity, and hence the average price must change in response to these. Each offerer or offer-taker will adjust their individual unique price for their Expected Parcels, and the emergent average price will change accordingly.

In the initial implementation of the framework, Economic Units do not consult the list of outstanding offers when adapting to current economic conditions. They only consider their ability to meet their needs in the past by making or accepting offers. Consulting the list of outstanding offers is planned as a future enhancement.

This updating of expected parcels reflects changes in lifestyle and expectations for households, and changes in business plans and strategies for firms. Thus this portion of the model could benefit from existing research in lifestyle transitions and business planning.

Time sequence of simulation

The simulation framework is meant to represent a subset of the transactions that might actually occur. For instance, the simulation framework might represent the transactions of a typical day in each year.

For transportation planning, it is important to calculate travel conditions on the transportation system as a function of the demand on the transportation system. Following the tradition of aggregate spatial economic models, the transactions of a typical day will lead to trips, and trips will lead to congestion, and congestion will lead to congested travel times. These congested travel times will change as the spatial economy and the physical transportation network change. Thus the travel conditions need to be updated periodically, perhaps annually.

These two considerations make it attractive to consider a "time step". All of the transactions for all economic units for a typical day can be generated, then the trips needed to support these transactions can be calculated, then the trips can be assigned to routes on the network using an equilibrium assignment procedure that assigns routes consistent with congested travel times. The congested travel times can be considered constant for a "time step" of one year.

The choice process considers one Expected Parcel at a time. Each Expected Parcel must have a chance of being considered in each time step. The list of offers must continuously evolve: it cannot be discarded at the end of the time step. Within these constraints, there are two different simulation methods that can be pursued:

1. Expected Parcels can be considered in a random order once each year, with offers lasting until the Expected Parcel is considered in the next time period, and expectations adjusted for each parcel as it is (re) considered

2. A discrete event simulation can be adopted, with the time of consideration for each Expected Parcel being "queued up" when the Expected Parcel was last considered by the Economic Unit, or when an offer is accepted by another economic unit.

Future work in developing a comprehensive modelling system

The framework is meant to be applicable for transportation planning. Most current research in transportation policy analysis models emphasises the "activity based" modelling system, where the *activities* that individuals engage in a day are the critical aspect of behaviour that leads to travel. The framework described here is somewhat different – the focus is on market and non-market *interactions* rather than on activities. This ties the transportation system in with the economy and may facilitate a more economic analysis of the benefits and costs of transport policy. Activity based transportation planning models focus on individuals, and how individuals fit their activities into their daily schedule. The framework described here has no representation of time-of-day, and individuals are not identified separately from their households. Work will need to progress on representing time-of-day and individuals before the framework can compete with activity based models in the transportation planning arena.

The system just described is a dynamic simulation of the transactions that occur in a spatial system between business establishments and households, with the location of the business or household playing a key role in the simulation. To be a full predictive planning tool, the system also needs to have the population of business establishments and households change over time. Research is also progressing on this front. The Oregon Statewide Model (Hunt *et al*,2001) contains a "Household Allocation" component which simulates the formation and dissolution of households, the birth and death of household members, and household choice of home location. Other ongoing research at the University of Calgary is working to develop a similar system for Business Establishments, modelling their formation and dissolution, growth and change, and location choices. These models are currently using the aggregate commodity exchange model described above (Hunt's generalization of the Martin Centre model.) Thus, work is progressing on two fronts: the microsimulation of heterogeneous spatial markets (described here) based on transactions between Economic Units; and the microsimulation of long term household and business dynamics based on an aggregate representation of markets. Eventually, the two works should merge, giving a microsimulation of long-term household and business dynamics based on a dynamic microsimulation of heterogeneous spatial markets.

The real estate market is fairly unique and is critically important to spatial planning. Eventually, even it could be represented using some of the ideas described here for microsimulation of heterogeneous spatial markets. Currently, however, separate processes are being used to simulate both land development (real estate supply), and household and establishment location decisions (real estate demand). The current emphasis of the system described here is day-to-day transactions and associated travel and shipments.

The framework was initially conceived with the intention that it would support a longer-term urban economic model that has a realistic representation of the formation of spatial clusters of complementary activities in urban areas. Such clusters are often highly specialised and spatially very small, with substantial pedestrian movement between the economic units in the cluster. The framework has been designed to allow unlimited spatial detail (without the Order n^2 performance degradation that occurs in zone-pair representations of interactions) and arbitrary diversity in the representation of the unique characteristics of the actors and their desired interactions. Thus the framework can represent the advantages of such micro-level clustering based on the unique characteristics and needs of Economic Units. The framework does not yet, however, represent spatial clustering since the framework has not yet been tied to location decisions. However it may be an important step in the right direction.

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