International Environmental Modelling and Software Society (iEMSs)
2010 International Congress on Environmental Modelling and Software
Modelling for Environment's Sake, Fifth Biennial Meeting, Ottawa, Canada
David A. Swayne, Wanhong Yang, A. A. Voinov, A. Rizzoli, T. Filatova (Eds.)
http://www.iemss.org/iemss2010/index.php?n=Main.Proceedings

Towards the Integration of Economic and Land Use Change Models

Hedwig van Delden[a] and Garry McDonald[b]
[a] *Research Institute for Knowledge Systems, Witmakersstraat 10, 6211 JB Maastricht, The Netherlands (hvdelden@riks.nl)*
[b] *Market Economics Ltd., P.O. Box 331 297, Takapuna, Auckland, New Zealand (garry@marketeconomics.co.nz)*

Abstract: Although in the past decades several attempts have been made to integrate economic models with land use change (LUC) models, none of them have been fully satisfactory. In this paper we analyse four different integrated models for policy support that include economic and LUC models. We describe several functional forms used to integrate LUC and economic models, highlighting the various strengths and weaknesses of each form, and in turn, suggesting possible pathways for improved integration. Analysing the concepts and underlying assumptions of both types of models show their vast difference. When integrating these models, underlying assumptions and limitations of the existing individual models are passed on to the integrated model. A proper integration therefore requires a thorough understanding of the underlying theories of both types of models and a solution at this theoretical level. We argue that concepts of evolutionary economics and -spatially explicit- agent based modelling, where creation of ideas and learning are embodied into fully integrated LUC and economic models, provide some key mechanisms for bridging the described gap. These approaches are however very data demanding and have -at least at present- major limitations in performing a proper calibration and validation.

***Keywords**:* Ecological economic modelling; Land use change modelling; Model integration, Cellular Automata, Agent Based Modelling, Evolutionary approaches.

1. INTRODUCTION

The first Integrated Spatial Decision Support Systems (ISDSS) capturing both land use and socio-economic inter-linkages appeared in the mid 1990s (Engelen et al., 1995). Since this time, the integration of land use and socio-economic models has involved integrating existing high resolution dynamic LUC models (based on techniques such as cellular automata) with formal sector based macro-economic models that do not have a high level of spatial detail. The notion that economic and land use change processes interact, is common knowledge (Castells, 1977; Harvey, 1985; Lefebvre, 1991). How to simulate this interaction in (integrated) models is not that straightforward. Both disciplines have co-existed for decennia and each has developed its own concepts and (modelling) paradigms. When integrating models from these different disciplines, underlying assumptions and limitations of the existing individual models are passed on to the integrated model. A proper integration therefore requires a thorough understanding of the underlying theories of both types of models.

In this paper we will analyse several ISDSS that integrate economic and spatially explicit LUC models and that aim to support planning and policy-making processes: LUMOCAP (Van Delden et al., accepted), WISE (Rutledge et al., 2008), Eururalis (Verburg et al., 2008) and MedAction (Van Delden et al., 2007). In the first three systems macro-economic models are coupled to LUC models, in the latter economics are incorporated into the LUC model. The ISDSS are selected in such a way that all of them include different types of economic models. The land use models incorporated are all dynamic simulation models. To provide the reader with a good understanding of the different concepts used by the various models, we will give a brief overview of the theoretical approaches in Section 2. In Section 3 we describe the four ISDSS mentioned above and detail the functional forms of the models used to integrate LUC and economic models as well as the various strengths and weaknesses of each form. Finally we will discuss the current challenges, draw some general conclusions and suggest possible pathways for improved integration.

2. METHODS USED IN ECONOMIC AND LAND USE CHANGE MODELLING

The integration of land use and economic models requires bringing together of two related, but often distinctly different, world views. The methods, concepts and terminology used, for example, by economists and land use modellers can be very different. In section 2.1, we provide a very brief overview of the models (with key concepts highlighted in italics) that regional economists have applied in relation to land use modelling. In section 2.2 we explain common concepts used in LUC modelling. Our attempt is not aimed at being comprehensive, but rather at providing background on key tools used in economic and land use modelling and, perhaps, more importantly, initiating discourse and reflection on the modelling paradigms we are inherently trying to integrate.

2.1 Formal sector based macro-economic models

Econometrics is concerned with developing and applying *statistical methods* to study economic relationships or principles (Frisch, 1933). It focuses on the statistical properties of key determinants underpinning economic behaviour, and in the case of land use modelling, often *extrapolation* patterns inherent in time series data to provide future forecasts for key socio-economic variables such as GDP, employment and exports. Because firms within an economy interact with each other, the observational data used in econometrics tends to capture complex equilibrium conditions. This has led econometricians to develop methods for estimating *simultaneous equations models* (e.g. capturing supply and demand characteristics of an economy). A key problem with the use of econometrics in modelling scenarios is that it often requires that we extrapolate historical trends to determine future states. Such patterns are, however, often peculiar to a series of events of policy interventions or market dynamics, which may not persist through time.

Input-output (IO) models provide a snapshot of the *structural interdependencies* between industries (e.g. agriculture, manufacturing, and services), primary inputs (e.g. wages and salaries, profit, imports, depreciation) and final demands (household consumption, government consumption and exports) for a given financial year within an economy (Miller and Blair, 2009). Input-output tables are presented in matrix format with row entries representing sales and column entries purchases. Using simple matrix algebra IO tables may be used as an analytical tool to study the short-to-medium implications of *comparative static* changes in demand (i.e. consumption, exports, and environmental emissions), or supply (e.g. wages and salaries, imports, and environment factors such land, energy, water etc), on an economy. Importantly, IO models capture not only direct, but also indirect (through supply chain purchases) and induced (through consumer spending) impacts associated with economic change. The key drawbacks of I/O models is that they are typically linear, ignore important investment (and often employment requirement) dynamic feedbacks, and take no account of price change.

Computable General Equilibrium (CGE) models employ detailed bottom-up *micro-economic theories* to establish a picture of a given regions macro-economy (Johannson, 1960; Rutherford, 2005). CGE models explicitly model the interconnectedness of agents (households, businesses, investors, government) within any economy, including allowing agents to modify their behaviour in light of economic change. As with IO, a key benefit of this approach is that it allows modellers to comprehensively measure direct, indirect and induced economic consequences results from these changes. CGE, however, extends IO to include feedbacks associated with investment, labour dynamics and price change. CGE models include non-linear functions (with *elasticities* determined via econometric analyses) covering both production and consumption. CGE models tend to be *recursively dynamic* (i.e. there are feedbacks between components within the model), but often neglect transitional dynamics (i.e. how economic agents change through time). Instead CGE models reports only on the resulting long run *equilibrium* or *steady state*. They are "solved" for a particular economic shock using numerical optimisation. Most CGE models, while mathematically pleasing, are concerned too academic to be useful in applied studies. Key reasons include (1) the data required to determine the elasticities (and also other data inputs) is often unavailable or extremely costly to obtain, and (2) complexities exist with integrating optimisation and LUC models.

2.2 High resolution dynamic land use change models

LUC models that have the objective to simulate spatially explicit dynamics are often based on self-organization or complexity theory (White and Engelen, 1993). They generate an organized but unpredictable behaviour of the land use system. This behaviour is represented by a large set of simple equations or rules that together create a complex behaviour that includes non-linear dynamics and emergent properties. They are simulation models that start with a land use map of the initial year and use a set of drivers (behavioural, institutional and physical) to calculate future developments. These models are exploratory and show what could happen, rather than what should happen. There is no ideal future, nor is there an assumption that the world reaches equilibrium in any point in time.

Cellular automata (CA) are a common means to implement the self-organisation approach. All LUC models in this paper incorporate a CA or use techniques related to CA and hence have the following characteristics: they are grid based applications in which each cell is in a possible state, i.e. occupied by a specific land use. Time progresses in discrete time steps and at each time step all cells update state (land use) simultaneously, based on the state of the previously time step, the neighbourhood of the cell and the transition rules that state under which conditions cell states change.

Most LUC models currently in practice, including the ones described in this paper, make use of a special form of CA, called constrained CA. In this type of model, area demands for each land use are determined exogenously, while these demands are allocated by the model. Furthermore, in most applications land use transitions are not purely based on the cell states in the neighbourhood, but on local characteristics as well, such as accessibility to infrastructure or the inherent suitability of the location for a specific land use. With these additional behavioural components the systems have been named 'relaxed' CA (Couclelis, 1985).

3. ANALYSING DIFFERENT APPROACHES TO MODEL INTEGRATION

The four selected integrated models are described below. A brief overview of each model is provided and the link between the economic component and the land use component is detailed. At the end of each section the advantages and disadvantages of the approach are discussed.

3.1 LUMOCAP – Dynamic Land Use change MOdelling for CAP impact assessment on the rural landscape

The LUMOCAP PSS is developed to assess the impact of the Common Agricultural Policy (CAP) on the land use and landscapes of the 27 countries of the European Union (Van Delden et al., accepted). The system incorporates models for agricultural economics, socio-economic regional interaction, land use allocation, crop choice and physical suitability and uses scenarios for climate change, socio-economic developments and policy alternatives as external drivers. It encompasses four spatial levels: EU-27, national, regional and local (1 km^2 grid for the entire EU and 4 ha grid for specific case studies). The temporal resolution of all models is a year and the time span of the system is from 2000 to 2030.

LUMOCAP integrates an econometric model, a dynamic multi-product supply model of EU agriculture, with local models simulating land use change and physical suitability. On a yearly basis the econometric model drives the expansion or decline of the agricultural area which is subsequently allocated on the local grid cells using a cellular automaton based LUC model. Based on the competition for space with other land uses, the agricultural land uses will be able to occupy more or less suitable locations. Moreover, suitability of locations is impacted by climate change and in particular changes in temperature and rainfall. After allocating the crop types at the local grids, yield is calculated for each location. Aggregate yield values per region are fed back to the agricultural economic model that uses these for the calculations of the production and area totals per crop type for the next year.

Integration between economic and LUC models is facilitated because both types of models use discrete time steps and operate on a yearly temporal resolution. This makes the feedback of information between components straightforward. Links to other economic sectors at macro-level are only included to the extent they are reflected in the historic data. Although the integration seems to work well, it should be noted that the econometric model heavily relies on historic time series and can therefore not deal very well with long-term scenarios, which is a main application domain of the incorporated LUC model.

3.2 WISE – Waikato Integrated Scenario Explorer

The Waikato Integrated Scenario Explorer (WISE) aims to support long-term integrated policy development and planning in the Waikato region in New Zealand by taking into account cultural, social, environmental and economic well-being (Rutledge et al., 2008; Huser et al., 2009). The system incorporates models at the level of the entire Waikato region (ecological economics), as well as district (demographics), sub-catchment (water quality) and local level (hydrology, land use and terrestrial biodiversity). Drivers for the integrated model are climate change scenarios, socio-economic drivers (e.g. fertility, mortality and migration rates, exports and consumption patterns), and policy alternatives (zoning regulations, impact restrictions and construction of infrastructure). The temporal resolution of all models is a year and the time span of the system is from 2006 to 2050.

WISE incorporates a sector driven economic model based on IO analysis. This model is an important driver for land use change in providing land use demand for a range of economic activities such as industry, commercial activities, dairying, cropping, and beef & sheep farming. The LUC model subsequently tries to allocate these demands at the local level. Only suitable and available locations are taken into account during the allocation. This avoids e.g. allocation of dairying land and industrial locations on steep slopes or urban development in conservation areas. When not all demands can be met, the competition for space between different actors is simulated by the allocation algorithm, and the final allocation is fed back to the economic model. The supply side of the economy is affected by this information and hence economic growth is less than would be expected by a purely demand-driven approach. Because the IO approach captures the interdependencies between industries, the availability of suitable land can restrict growth for different economic sectors.

The key strength of the WISE approach is the integration of available resources in the supply side of the economic model, simulating how physical and institutional restrictions on land resources are limiting the land supply and hence economic growth. Furthermore, this approach has the ability to capture the interdependencies (i.e. supply chain linkages) between industries, and in turn, changes in land use requirements across all industries.

A drawback of the IO model is that this is a linear model and interdependence between industries is assumed to be constant with no technological change. This makes the model less suitable for more creative and long-term scenarios.
When implementing the interactions between the land use and economic components a main difficulty was experienced. For the macro-economic model to operate correctly, the demand and supply side should be in equilibrium for a single year. Because the demand side impacts on the LUC model and the supply side is affected by the LUC model, equilibrium could only be obtained through an iterative procedure between the LUC and the economic component, which would have to be carried out during each time step. Such a procedure would however not match the simulation approach of the LUC model in which action and reaction are modelled over time. After reviewing several alternatives and investigating their results, it was decided to divide the demand and supply calculations over two time steps. This solution is conceptually not ideal (nor is the other solution of iterating between the economic model and the LUC model in the same time step), but was favoured because of its shorter execution time (which was important for the use value of the ISDSS) and its fit with the overall dynamic nature of the integrated model.

3.3 Eururalis

Eururalis provides a tool for a structured discussion between policy makers, stakeholders and scientists about the future of the rural areas of Europe. Results are calculated using a modelling chain including three existing models: an economic model, an integrated assessment model, simulating the impacts of CO2 concentrations and climate change on the agricultural sector and natural biomes, and a LUC model. 'By combining the economic and integrated assessment model the ecological consequences of changes in agricultural consumption, production and trade can be visualized' (Verburg et al, 2008). The tool provides information at local (1 km^2 grid), regional, national and cluster region level for 2000, 2010, 2020 and 2030.

Economic developments are calculated using LEITAP, a CGE model at world level based on the standard GTAP model (https://www.gtap.agecon.purdue.edu/models/current.asp). Changes in LEITAP compared to GTAP are documented in Van Meijl et al. (2006). In an iterative procedure LEITAP and the integrated assessment model IMAGE calculate the agricultural land use changes at the level of individual countries inside Europe and for larger regions outside Europe (Van Meijl et al., 2006). At the same time, these models also calculate changes in other sectors of the economy which are indirectly related to land use. This information is used in a series of simple models. For the industry and services sectors the changes in sector size are translated into land requirements for these sectors. For the natural and residential land use types the claims for land area are based on the exogenous drivers. A spatially explicit LUC model (CLUE-s) finally allocates land use change based on competition between different land uses and the use of spatial allocation rules while including various environmental and spatial policies (Verburg et al., 2008).

Strengths of this approach are the inclusiveness of the economic sectors allowing for an interaction between those sectors. Although there is interaction between the models at global/national level, a waterfall approach is used for the link between the global/national models and the local model: first land use demands are calculated and subsequently these demands are allocated on the grid; there is no feedback from the local level land use to the economic model omitting the feedback from the available land resources to the economy.

3.4 MedAction – Mediterranean Action

The MedAction Policy Support System (PSS) supports regional development and desertification, focusing on sustainable farming, water resources and land degradation in arid and semi-arid regions (Van Delden et al., 2007). MedAction consists of several sub-models that are integrated in a single model that simulates development in the region up to 30 years in the future, using 2000 as initial year. Individual components incorporated in MedAction include: a weather generator and models for hydrology, plant growth, salinisation, erosion and sedimentation, transitions in natural vegetation groups, crop choice land use and land management. External drivers include climate change and demand for land from international and national economic and demographic growth. The system includes a wide range of policy options, amongst others subsidies, taxes, zoning regulations, reforestation, decisions on water use and extraction, water pricing and construction of infrastructure. Impacts are assessed by means of a range of policy-relevant indicators that are aggregated into three headline indicators: water shortage, environmentally-sensitive areas and long-term agricultural profits.

MedAction makes use of external macro-economic drivers, which are converted into land use demands for economic functions, such as industry, commerce, tourism and agriculture. The LUC model specifies first where agricultural area will be located based on the competition for space with the other land uses. Next, a crop choice component determines which crops will be grown in the agricultural areas. The economic component of MedAction is incorporated in this crop choice model. For each location a utility based function calculates on a yearly basis what crop will be grown. Elements included is this equation are financial (market prices, costs, subsidies and taxes), physical (yield) and social (willingness to change). Financial elements are included as external drivers. The yield and expected yield of substitute crops is calculated by the bio-physical components. When farmers are not able to make a profit, agricultural land becomes abandoned and converts to natural vegetation, thus impacting on the other land use classes.

The main advantage of this approach is that economic drivers are integrated in the LUC models, making the utility approach an integral part of the land use choice. What is lacking in this approach is the link to macro-economic behaviour. Demand is reflected in the market prices, which are exogenous to the model. The regional supply does not have any impact on the agricultural economy of the country or the world, an assumption that is hard to back up for most agricultural regions in the current age of globalization; the interaction of agricultural with other economic sectors is only included in the competition for space at local level, while in reality this interaction has a much wider impact.

4. COMPARING DIFFERENT APPROACHES

All four above-mentioned approaches have integrated land use change and economics. The linkage between macro-economic models and LUC models is typically achieved through a static mapping of sector definition and land use class and is often one-way. LUMOCAP and WISE are exceptions to this by also creating a feedback from the LUC model to the macro-economic model. In MedAction, economic principles are incorporated in the local LUC model.

Although the four ISDSS described in this paper have to some extent succeeded in linking both types of processes, none of the approaches has found a procedure that is fully satisfactory. The problems experienced in this integration do however not stand on itself and are can be found in various other applications that link economic and LUC models (see e.g. Sieber et al., 2008). A key failure of most approaches is that they focus on integration of existing predetermined models as derived from their parent disciplines. The problems are hence closely related to the type of economic model included.

The use of econometric or regression based models, such as LUMOCAP, tends to be favoured in the integration of LUC and socio-economic models because of its –often yearly– temporal resolution which allows for an easy integration with dynamic LUC models, also often operating at the same yearly time step. A link between the economic model in LUMOCAP and any resource model is very difficult, because the lack of resources does not impact on the demand. This is however not a general limitation of econometric models, but a result of the specific choices made in the development of LUMOCAP. The selected economic model only represents the supply side and is therefore not sensitive to limited resources, such as land, water or human resources.

Furthermore, econometric models possess only limited value in assessing emerging behaviour as they attempt to predict future states of key driving economic variables through known historical patterns or trends. More importantly, the underpinning causal mechanisms, as characterized by feedback loops, time lags and non-linearities are typically overlooked or omitted, resulting in an application domain of short term spatiotemporal dynamics. It is worth noting that also comparative static implementations are often driven by econometric or regression analyses and, hence, are susceptible to the same underlying assumptions.

The main benefit of using IO and CGE models is that they capture not only direct, but also indirect (through supply chain purchases) and induced (through consumer spending) impacts associated with economic change. The dynamic link between LUC and economics in WISE thus shows the impact of limited (land) resources not only on the sector for which the demand cannot be fulfilled, but also on all other sectors. A key benefit in using CGE over IO models is that recursive dynamics within an economy (e.g. feedbacks through price changes, labour markets, and household spending) can be captured in the land use dynamics. Nevertheless, several problems exist with this approach: (a) CGE models rely on optimization algorithms to determine long run equilibriums, (b) derivation of the equilibrium typically ignore transitional dynamics, and (c) while the production functions used in CGE are dynamic, economic interdependence occurs through the a nested linear Leontief (IO) matrix – with its own underlying linear assumptions as identified above.

The equilibrium approach of the above-mentioned economic models poses conceptual conflicts with the simulation approach of the dynamic LUC models. A result of these conflicts became apparent in the dynamic interaction between both types of models in WISE. Using a waterfall approach with a one-way interaction seems to bypass this issue, but in reality only neglects to deal with it: making an equilibrium assumption for a future year, deriving land use demands from this and subsequently interpolating these demands and allocating them on a grid is questionable in the least.

Many recent LUC models successfully integrate micro-economic principles into their operation. MedAction is an example of this as are many of the current spatially explicit agent based approaches to LUC modelling. But, we are still left with many exogenous sector-based macro-economic variables unaccounted for and practical applications that include the dynamic interaction between macro-economics and agent-based approaches are not yet available.

5. CONCLUSIONS AND RECOMMENDATIONS

In this paper we have compared four ISDSS in the way they have integrated land use and economics. LUMOCAP, WISE and Eururalis link macro-economics to land use, while MedAction integrates micro-economic principles into its operation. All have in some way succeeded in making the interaction, but none have done so fully satisfactorily. Problems are mainly the results of conflicts in the underlying theories: static equilibrium versus dynamic simulation, and the focus of most macro-economic approaches on short-term prediction based on an extrapolation of historic trends, instead of a dynamic approach that captures cause-effect relationships and transitions.

We believe that for an improved integration the theoretical foundations of economics and land use change processes should receive more attention and that integration between these disciplines should start from a theoretical basis, rather than a software coupling between existing models. Evolutionary economic theories such as those promoted by Nelson and Winter (1982), and the applications of "endogenous growth" theory (Lucas, 1988), embodying the creation of ideas and learning, provide some key mechanisms for bridging the described gap. Linking models incorporating these theories with spatially explicit agent based approaches could improve the representation of human behaviour in the model and facilitate the link between macro-and microeconomics. These models are however very data demanding and have major limitations in performing a proper calibration and validation. We advocate that the trans-disciplinary nature of integrating not only LUC and economic, but also biophysical models, has a strong fit with the emerging principles of ecological economics (Ayres, 2001). LUMOCAP and MedAction are examples of ISDSS that show the benefit of linked socio-economic and bio-physical models, while WISE shows the potential of including locally defined resource limitations on macro-economic behaviour.

ACKNOWLEDGEMENTS

The New Zealand Foundation for Research, Science, and Technology funds the Creating Futures project (ENVW0601) and the Sustainable Pathways II project (MAUX0906), the European Commission has funded the development of LUMOCAP (FP-6 SSPE-CT-2005-006556), and the DeSurvey IAM (FP-6 IP 003950).

REFERENCES

Ayres, R.U., The minimum complexity of endogenous growth models: the role of physical resource flows, *Energy,* 26(9), 817-838, 2001.

Castells, M., *The Urban Question: A Marxist Approach*, Arnold, London, 1977.

Couclelis, H., Cellular worlds: a framework for modelling micro-macro dynamics, *Environment and Planning A,* 17, 585-596, 1985.

Engelen, G., R. White, I. Uljee, and P. Drazan, Using Cellular Automata for Integrated Modelling of Socio-environmental Systems, *Environmental Monitoring and Assessment*, 30, 203-214, 1995.

Frisch, R., Editor's Note, *Econometrica,* 1, 1-4, 1933.

Harvey, D., *The Urbanization of Capital*, Blackwell, Oxford, 1985.

Johansen, L. *A Multi-Sectoral Study of Economic Growth,* North-Holland Pub. Co, Amsterdam, 180pp., 1960.

Lefebvre, H., *The Production of Space* (D. Nicholson-Smith, Trans.), Blackwell, Oxford, 1991.

Lucas, R.E., On the mechanics of economic development, *Journal of Monetary Economics*, 22, 3-42, 1988.

Miller, R.E. and P.D. Blair, *Input-Output Analysis: Foundations and Extensions,* Cambridge University Press, New York, 2009.

Nelson, R.R. and S. Winter, *An evolutionary theory of economic change,* Harvard University Press, Cambridge University MA, 1982.

Rutledge, D.T., M. Cameron, S. Elliott, T. Fenton, B. Huser, G. McBride, G. McDonald, M. O'Connor, D. Phyn, J. Poot, R. Price, F. Scrimgeour, B. Small, A. Tait, H. van Delden, M.E. Wedderburn and R. Woods, Choosing regional futures: challenges and choices in building integrated models to support long-term regional planning in New Zealand, *Regional Science Policy & Practice,* 1(1), 85-108, 2008.

Rutherford, T.F., *GAMS – MPSGE Manual*, Unpublished Report, GAMS Development Corporation, Washington DC, 2005.

Sieber, S., M., Müller, P. Verweij, H. Haraldsson, K. Fricke, C. Pacini, K. Tscherning, K. Helming, T. Jansson, Transfer into decision support: the sustainability impact assessment tool (SIAT), In: K. Helming, M. Perez-Soba, P. Tabbush (eds.), *Sustainablility Impact Assessment of Land Use Changes,* Springer, 2008.

Van Delden, H., T. Stuczynski, P. Ciaian, M.L. Paracchini, J. Hurkens, A. Lopatka, O. Gomez, S. Calvo, Y. Shi, and R. Vanhout, The LUMOCAP policy support system: dynamic land use change modelling for impact assessment of agricultural policies on the rural landscape, *Ecological Modelling,* accepted.

Van Meijl, H., T. van Rheenen, A. Tabeau and B. Eickhout, The impact of different policy environments on land use in Europe, *Agriculture, Ecosystems and Environment*, 114, 21-38, 2006.

Verburg, P.H., B. Eickhout and H. van Meijl, A multi-scale, multi-model approach for analyzing the future dynamics of European land use, *The annals of regional science,* 2008.

White R. and G. Engelen, Cellular automata and fractal urban form: a cellular modelling approach to the evolution of urban land use patterns, *Environment and Planning A,* 25, 1175-1199, 1993.