18. Evolutionary games in cities and urban planning

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1. INTRODUCTION

Cities are prime examples of complex adaptive systems (Portugali 2000; Batty 2008; Batty and Marshall 2012; Portugali et al. 2012). They emerge as the (un)intended coordination among many actors and as a by-product of, among others, social relations of control, domination and power. More than inorganic agglomerations of concrete, cities can be seen as spatial forms of social production (Lefebvre 1991). As a stage for interactions between self-regarding beings – potentially with antagonistic drives – cities are (also) subject to the pasture dilemmas so clearly put by Garret Hardin in his 'The tragedy of the commons' (Hardin 1968) where, in the absence of externally or self-enforced rules, individuals may threaten the sustainability of the common good. Resource depletion, crime, overpopulation, environmental degradation, inequality and social conflict are henceforth examples of negative externalities that can undermine the sustainability of cities in general. Cities also create a complex ecosystem, where citizens' work, knowledge, cooperation or ideas interact in a non-trivial way leading to returns that benefit everyone (Bettencourt et al. 2010). These dynamics may be potentiated by the use and integration of large-scale datasets that cities effortlessly aggregate, creating a new type of common good. Understanding how to cope with these challenges while taking advantage of the extraordinary capacity of humans to cooperate can positively affect the living standards of a considerable fraction of humanity: The percentage of world population living in urban areas surpassed the 50 per cent mark in 2018 (55 per cent) and is expected to reach 68 per cent by 2050 (United Nations 2018).

In this context, planning can be employed both to avert cities' difficulties and to sustain collective good. Planning may be understood as an attempt to shape the future by current acts and practices (Wildavsky 1973). How and when to plan are, however, timeless questions without lasting answers. Modern planning was initially understood as a top-down, centrally driven process where the State intervened to secure the common good (Friedmann 1987; Taylor 1998), in line with the prescription of Garret Hardin. This rational comprehensive planning approach assumed that, by means of science, it could be possible to predict the future (for example, future demand for housing and roads) and to plan accordingly. Its basic tools were the master plan, the development plan and zoning. This planning model ended up in failure: the future proved to be unpredictable, master and development plans were never implemented as intended, while zoning entailed the 'death' of cities (Jacobs 1961).

The limitations of a rational view of planning are further revealed by several unsuccessful stories (Taylor 1998) and because planning has, meanwhile, changed from a two-sector setting – between public institutions and private bodies – to a three-sector arena – comprising public, private and civil actors.

The limitations of top-down planning brought to light governance alternatives set up in a bottom-up fashion, whose success was demonstrated by (Ostrom 1990). This realization called for alternative strategies that could also promote a bottom-up, self-organized governance. Two interrelated alternatives emerged: communicative or collaborative planning (Innes 1995; Healey 1996) and, more recently, the complexity approach. Communicative planning, which was directly inspired by Habermas's (1984) theory of communicative action, replaced prediction with urban vision by means of the participation of the third sector (for example, non-governmental organizations and local communities) in planning committees. In the complexity approach, there are two views about the role of planning: (1) planning as intervention, in an otherwise self-organized city and (2) planning as participation (where each urban agent is a planner at a particular scale). In this last view, planning as an integral part of the system it intervenes in is also subject to dynamics of adaptation and self-organization, thus requiring a change from prediction-based planning to rules-based planning (Portugali 2011).

These renewed approaches are not alien to problems associated with rationally bounded agents (Forester 1982), conventionally viewed as myopic and inherently suboptimal decision-makers. Bottom-up approaches may (also) lead to lock-in states that prevent the realization of social good originating in coordination failures. In this instance, actors interact strategically following individual preferences that include, for example, incentives, sanctions, coercion, bargaining and competition, but also different power positions, conflicts between local and global interests of the actors involved, and the weakening of the state. This complex setting calls not for rivalry between top-down and bottom-up approaches, but for the realization of their nested nature. In addition to this strategic reasoning, if we regard individuals as influenced and influencing agents embedded in large communities, it becomes essential for the planning endeavour to understand and, if possible, predict, control and adapt to the long-term dynamics of strategies employed. Thus, game theory, viewed as a planning tool, should not only be applied in a static way, but also motivate dynamic analysis of how city actors' decisions unfold over time, turning evolutionary game theory (EGT) into a relevant candidate to address this type of problems (Encarnação et al. 2018).

As we exemplify in this chapter, EGT enables the study of the strategic dynamics resulting from diverse decision-makers (players), strategies and interaction rules. Adopting available strategies in space and time leads to a dynamic process, whereby individuals influence and are influenced by others. Evolutionary game theory focus on the properties and characteristics of the population as this co-influence dynamics unfolds in time. After providing more details on classical game theory and EGT (section 2), we highlight the potential role of EGT in planning (section 3). We then focus on the particular case of dynamics between different types of city players – representing various sectors of society. To this end, we exemplify the application of EGT concepts (section 4), following the analysis proposed in a recent set of studies (Encarnação et al. 2016a, 2016b; Santos et al. 2016). We focus on the dynamics of strategy adoption and long-term behaviour of individuals from public, private and civil sectors, providing the existence of different mechanisms (for example, taxes, subsidies, electoral pressure and civil activism) at work within and between sectors. We end the chapter by discussing the results obtained, framing them in a wider planning perspective and elaborating on future research avenues that may rely on EGT to guide urban planning (section 5).

2. A BRIEF INTRODUCTION TO (EVOLUTIONARY) GAME THEORY

Planning may be conceived as an attempt to shape the future through present acts (Wildavsky 1973). This endeavour requires anticipation of the effect of different policies, in order to select (today) the acts that most likely materialize the planners' intentions (tomorrow). Linking acts and consequences across time is challenging, to the same extent that predicting is difficult – especially the future, as in the famous quote attributed to Niels Bohr. Planning often ignores that actions induce population adaptations, which in turn change the environment conditions from where the planning project departed, rendering them inexact and, by *force majeure* suboptimal. Planning should be approached with just-in-time strategies, allowing incorporating the natural features related to planning of a complex adaptive system (Portugali 2000; Alfasi and Portugali 2004; Levin 2006; Miller and Page 2009; Lo 2017). This endeavour requires improved conceptual and predictive tools. The object being planned (from land to transportation systems or markets), and whose dynamics should be comprehended and predicted, may differ in size, temporal scale, predictability and control. The conceptual tools employed must be adapted accordingly. Planning may require understanding how infrastructures respond to temperature variability, resorting to chemistry and material sciences; planning may require anticipating the weather or shoreline dynamics for the coming decades, demanding meteorology; planning may require calculating the net return of old and current investments, relying on finance; and planning may benefit from upcoming health and sanitation insights, or knowledge about new transportation and communication means. Planning calls for a myriad of disciplines but, at a fundamental level, planning requires comprehending, predicting – or at least reason about – the responses of decision-makers to environment, social, economic and political challenges. In these scenarios, it is fundamental to understand dynamics of cooperation, conflict and coordination among city actors.

The discipline of planning evolved to reflect how coordination between individuals is understood (planning theory) and dealt with (planning practice). The very idea of coordination in planning has evolved consistently with societal changes. Reff et al. (2011) review the evolution of the coordination concept in public governance through the lens of public administration, organization and planning theories. Common to all three theories is the definition of coordination as collective action that results from the successive adjustment of actions by different actors. This notion implies that actions, and thus decision-making, are conditioned by the way others act. These interdependences introduce new levels of uncertainty to the urban game that planning tries to control, but of which it is also a part of. Considering strategic reasoning in planning is thereby central, in a way that is very similar to that embodied in the realm of game theory (GT).

Game theory is a sub-field of applied mathematics that gained momentum after the seminal work of John von Neumann and Oskar Morgenstern, with the publication of *Theory of Games and Economic Behavior* in the 1940s (von Neumann and

Morgenstern 1947) – despite some initial definitions of GT being attributed to Émile Borel (von Neumann and Morgenstern 1947; Fréchet 1953). Game theory can be understood as the science of rational decision-making in the context of strategic interactions (Osborne 2003). By rational decision-making is meant that individuals will behave following a set of well-defined preferences (for example, Alice prefers spending time in a park rather than commuting). Strategic interactions refer to situations in which the outcomes' value depend on the decisions made by the players involved (for example, the enjoyment of Alice in the park depends on how many people also use it). In an urban context, it is evident already that GT can serve the planner (for example, guiding how to structure traffic to prevent jams), the citizen (for example, informing Alice which route to take in order to maximize leisure time at the park), the analyst (for example, explaining why only some routes get congested) and the fortune-tellers (for example, predicting which route is most likely to be selected by rational agents). Even if predictions cannot be accurately made, GT provides, at the very least, a way to (1) formalize the essence of the strategic interaction, serving as a potential filter to help one disregarding irrelevant details, (2) abstract the challenges associated with particular interactions and identify principles that apply to a range of problems (identifying old solutions to new conundrums), and (3) communicate in a straightforward fashion how modifying our behaviour may affect social welfare. Several interaction paradigms are well studied and allow us to identify common behaviour patterns and solutions at ease. In two-player, two-strategy situations, interactions of interest often configure social dilemmas with the ingredients of a prisoner's dilemma, snowdrift dilemma or stag-hunt dilemma (Macy and Flache 2002), whose payoff table is summarized in Table 18.1.

In all those situations, individuals decide to use one of two possible strategies: say, cooperate or defect. The socially desirable outcome is achieved if individuals simultaneously decide to cooperate (R > P). However, incentivizing cooperation is not easy: In a prisoner's dilemma, individuals are always better off by defecting, regardless the strategy selected by their peers: both the temptation to cheat (T > R) and the fear of being cheated upon (P > S) are present. In a snowdrift dilemma, if an individual cooperates and

Table 18.1 Payoff table of two-person two-strategy social dilemmas

		Column player	
		C	D
Row player	C	R;R	S;T
	D	T;S	P;P

Note: Individuals can adopt one of two actions, cooperate (C) or defect (D). Each table entry reports the gains for the row player (first quantity) and column player (second quantity), for each possible combination of strategies. The peculiar relationship between the quantities obtained by the row player and column player reflect that the game is symmetric, that is, both players get the same payoff whenever confronted with equivalent situations. If both individuals cooperate, they both receive reward (R). When a cooperator plays with a defector, the first receives S (sucker's payoff) while the latter receives T (temptation). If both individuals defect, both receive punishment (P). A prisoner's dilemma results from the condition S < P < R < T, a snowdrift from P < S < R < T and a stag-hunt from S < P < T < R.

Source: Skyrms (2014).

another defects, then no one has interest in modifying their strategy (T > R but S > P): the temptation to cheat may incentivize high levels of defection, and too much cheating becomes detrimental. In a stag-hunt dilemma (P > S but R > T) there is only fear and no temptation: individuals have a risky option that maximizes their payoff (to cooperate or, according to the game metaphor, aiming to hunt a stag), yet to defect is the safer option (defect, that is, going for the hare); thus fear may prevent cooperation (Macy and Flache 2002). In city interactions, taking good care of a building façade or individual garden suggests a stag-hunt dilemma: the value of keeping everything tidy is contingent on the decision of each neighbour, so that if everyone puts effort into cleaning their property (or if no one does) then there is no incentive to deviate from that status quo. The possibility of sharing the commuting with a neighbour giving him or her a ride (or sharing a Wi-Fi account) may introduce a prisoner's dilemma, where a social benefit can be created at the expense of the cooperator. Finally, the dilemma of removing the snowdrift blocking a common road introduces (unsurprisingly) a snowdrift dilemma.

Despite the multiple advantages of GT, two main criticisms are typically made of classical game theoretical analysis: first, GT provides a toolkit for a static study of interactions. That is, by resorting to solution concepts of classical GT, we may learn which strategies configure an equilibrium; it remains difficult to reason about how particular strategies might come to be played – and the ensuing dynamics. Second, GT relies on extremely strong rationality assumptions, by supposing that individuals know the actions that they themselves and their rivals can employ, together with the costs or gains associated with these actions. In reality, people may lack that information, and often individuals resort to simple heuristics to adapt their behaviour instead of exactly computing the expected returns associated with each combination of actions. Individuals may imitate each other (Lieberman and Asaba 2006; Rendell et al. 2010) or change their actions through trial and error (Erev and Roth 1998), learning with their own experience.

In biology, a new toolkit was eventually proposed: evolutionary game theory (Lewontin 1961; Smith and Price 1973; Smith 1982). Initially, the goal of EGT was grasping mathematically how particular behaviours evolve through natural selection in animal species; for example, conflict (Smith and Price 1973) or cooperation (Trivers 1971). Soon after, social scientists started applying EGT to circumventing the drawbacks of classical GT, listed above (Weibull 1997). All previous paradigmatic dilemmas introduced (prisoner's, snowdrift and stag-hunt dilemmas) can be understood from the standpoint of a dynamical, population perspective (Santos et al. 2006). Regarding urban planning, the biological inspiration to address strategic dynamics seems particularly appropriate: We may conceive cities as concrete jungles, in which individuals from many different sectors (as species) interact embedded in ecologies that constantly adapt over time. This multi-sector interaction paradigm is elucidated in section 4.

In addition to introducing a dynamical perspective and relaxing the rationality assumptions, EGT helps to refine important equilibrium notions of classical GT. While in GT we are often interested in identifying Nash equilibria, that is, situations from which no part is interested in deviating, unilaterally (Nash 1950a) – in Table 18.1, both individuals choosing D would be a pure Nash equilibrium if S < P – with EGT it is of corresponding interest to determine evolutionary stable strategies (ESS), that is, strategies in a population that cannot be invaded by any other mutant strategy (Smith and Price 1973). Again resorting to Table 18.1, a strategy D would be an ESS if P > S or, if P = S, then T > R (Nowak 2006). This means that a mutant strategy (C) must either perform worse against the incumbent (D) or, if performing equally well, perform worse against C than D against C. Moreover, EGT allows the easy determination of population equilibria, that is, population configurations at which point no configuration changes will occur (in the absence of mutations) and, importantly, determines the nature of these equilibria. The analogy with mixed Nash equilibria is evident, although here both the determination of the equilibria as well as their nature need not invoke any additional probabilistic assumptions. Unlike static game theory, EGT not only allows us to identify the possible equilibria, but also to understand to what extent these equilibria are attainable, depending on where we are in the configuration space (that is, the fraction of individuals adopting different strategies). As well as adding concepts such as stability to (mixed and pure) Nash equilibria, EGT enables us to use the well-developed analytic machinery of differential equations, since the process of strategic adoption becomes a dynamical system described by the well-known replicator equation (Taylor and Jonker 1978). These tools can be handy for comprehending dynamics associated with city planning (Santos et al. 2016; Encarnação et al. 2016a, 2016b).

The role of EGT in planning can be foreseen if we regard individuals as influenced and influencing agents embedded in large communities, such that it becomes useful to understand, and thus predict, in the simplest scenarios, the long-term dynamics of strategies' adoption. By using concepts from EGT, we can characterize collective behaviours that emerge from individuals' decisions (Schelling 1978), such as the decision to live in a city or neighbourhood, as traits that spread and eventually endure in space and time owing to some perceived advantage over other places in which to live. Evolutionary game dynamics can account for different types of players, representing various sectors of society. For that, we employ multi-population (Weibull 1997) or asymmetric models (Samuelson and Zhang 1992; McAvoy and Hauert 2015). In urban games, we consider the interaction of players from multiple sectors, such as the civil, private and public sectors. The integration of a multi-sector framework, where interdependencies between and within sectors are allowed, may provide new insights on the intricate nature of cities' dynamics. With these stylized models, we can account for the role of incentive mechanisms between sectors and peer-influence dynamics (for example, imitation and social learning) within sectors. Similar to how fitness drives evolution in genetic evolution, we can assume that strategy adoption depends on perceived success: individuals may compare how they perform relative to their peers, which may lead them to adopt a different behaviour. Relative success associated with a given behaviour will lead to its proliferation in a population of city actors, in a similar way to how variants with a relative advantage will reproduce more and, as a result, outcompete other variants in biological populations.

Altogether, adopting an evolutionary game theoretical perspective over planning can be advantageous for three reasons. (1) It allows reasoning mathematically about different aspects of conflict or cooperation that a particular policy (or plan) may introduce, both within and between city sectors. (2) EGT permits reasoning about the lock-in states that different sectors may fall into, whose stability analysis may provide a justification for observed coordination failures or allow testing solutions that circumvent such states (the models reviewed will shed light on how coordination between sectors can be tamed to achieve socially desirable outcomes). Finally, (3) EGT allows us to explicitly consider the frequency-dependent nature of planning. We assume that strategy reproduction is frequency dependent, that is, contingent on how each actor and sector is performing at a given moment in time, and how represented they are in the entire city population.

3. EVOLUTIONARY GAME DYNAMICS IN CITY PLANNING: FROM LAND USE TO ILLEGAL SETTLEMENTS

Social dilemmas are characterized by two main properties: (1) individuals have a greater benefit by adopting non-cooperative strategies, and (2) all individuals would be better off if they all had cooperated (Dawes 1980). In its simplest interpretation these two properties reflect conflicts between individual and collective interests – the type of situations in which planning finds a large part of its theoretical and practice reasoning. How society uses and organizes space (a common and finite resource), is one evident example of a social dilemma that urban planning faces, with land classification and zoning schemes constituting the archetypal planning instruments for its regulation. These regulate the use of land by defining rights and restrictions on property rights. They are discretionary instruments available to, for example, municipalities that aim to manage urban growth and protect the territory as a common good. Also, space functions as a driver for development and growth and, pragmatically, as an important funding source for municipalities from which dynamics of competition can, and do, emerge. Thus, one of the basic questions in urban planning is to know how much space should be allocated to, let us say, urbanization and construction. There is no definitive answer to this question and a great deal depends on policy and political agendas, themselves mutable in space and time. Each municipality will look to its own territory and define via a master plan, typically a ten-year development strategy. However, municipalities do not exist in isolation; they are part of a wider, interrelated territory. A best option for one municipality can have detrimental impacts in an adjacent or nearby municipality.

To illustrate this complex dynamics, we can rewrite Table 18.1 as a game between two municipalities – our players. When designing their master plan, each municipality can adopt one of two strategies: Constrain or Maintain the urban growth model. Let us assume that the total combined capacity to build is four (arbitrary units). When players align their strategy they equally share this construction capacity, and hence receive equal payoffs. When both adopt strategy Maintain, each will get a payoff of two. By contrast, when both adopt the Constrain strategy they not only share the investments, but also receive, arguably, an extra payoff point for increased sustainability levels – each receiving a payoff of three. This payoff advantage is informed by the transformation of policies and planning agencies worldwide as a result of new scientific and technical knowledge, together with new ways and demands of living, sustainability, governance and quality of life (Montgomery 2013; Sennett 2018). Finally, when strategies do not align, the municipality that does not constrain growth will receive in full the payoff available (in this instance, four) while the other municipality receives zero (Table 18.2).

Payoff Table 18.2 follows a (symmetric) prisoner's dilemma (PD) structure characterized by the inequalities $T > R > P > S$. The best option for each municipality is to independently choose Maintain, leading to the equilibrium Maintain/Maintain. Once again, the dilemma arises because, despite Maintain being the best move, if both municipalities adopt this strategy, it will bring a lower return than mutual adoption of

Table 18.2 Payoff table for two municipalities

		Municipality B		
		Constrain		Maintain
Municipality A	Constrain	3;3	→	0;4
		↓		↓
	Maintain	4;0	→	**2;2**

Note: Municipalities can adopt one of two strategies: Constrain or Maintain urban growth model. The table reports the gains for both players, for each possible combination of strategies. Arrows indicate the preferences of municipalities (vertical for municipality A and horizontal for municipality B). Bold is the equilibrium of the game.

Source: Rasmusen (1994).

Constrain measures. Moreover, if the Maintain equilibrium co-occurs with fragmented and dispersed growth, evidence shows that costs of infrastructure and facilities or loss of natural resources can become significant (Carvalho 2013). However, the (immediate) future is often too distant and not easily discounted (Frederick et al. 2002; Levin 2012), especially when decisions are framed in election cycles. We could also argue that following assumptions in PD-like games, both municipalities would not communicate with one another, thus increasing the perceived risk in constraining growth; that is, neither municipality would have any incentive to change from Maintain when Constrain is open to free-riders.

This game, though simple, can alert us to the importance of understanding strategic decision-making in real planning situations. Overall, it is a convenient starting point – trading specific details for generality and abstraction power – from which more complex models aiming at specific contexts could be built. For instance, we can envisage scenarios where an external entity, such as the central administration, would apply sanctions, which would reduce the payoffs of strategy Maintain to zero. In many countries, non-compliance with centrally designed guidance can have severe consequences, for example, non-approval of master plans, suspension of licensing mechanisms or, in European countries, impediment of application for European funds, being just a few examples. In that case, the equilibrium of the game would change to the alignment of the strategy Constrain.[1] Examples abound in which the unwillingness, inability or failure to actively intervene promote undesired outcomes, such as growth of dispersed and fragmented peripheries and cities (Carranca and Castro 2011), which in turn contributed to the loss of natural and agricultural areas (Encarnação et al. 2012), increased costs for municipalities with infrastructures (Carvalho 2013), and social amenities and facilities (Pereira 2004).

Planning games can also occur at both vertical and horizontal levels. Scale matters and levels are interdependent. Also, EGT benefits from a long tradition of analysing conflicts at different, interrelated scales in ecological contexts (Levin et al. 2012). As an example, the above-mentioned top-down solution, however successful in many cases, can give rise to other or similar social dilemmas at the scale of cities, communities and individuals. Importantly, planning becomes part of the game, as in general complex adaptive systems – a player whose strategic decisions affect, but are also contingent to, those of other players in society. For example, as master plans are approved and come into force, property owners' rights will be differently affected by means of an artificial limit created by zoning schemes that aim to protect the territory as a sustainable collective good. In this regard, the discretionary effect of planning itself creates a social dilemma, since by its own action it alters land rents and corresponding added value. This, in turn, will change the behavioural response of property owners. Therefore, planning should account for this uneven distribution of individual rights, and develop mechanisms for equitable solutions and compensation systems (Carvalho 2012) or put into practice land readjustment schemes (Hong 2007). The dilemma can then become a bargaining game, where there is the potential to achieve mutual benefits but where players depart from divergent interests (Nash 1950b; Binmore 1990). Models of this type can help understand how players could reach an agreement and how benefits would be distributed. Different models of bargaining can be used and adapted to the problem and conditions at hand, possibly taking into consideration the players' utility functions, information, risk aversion, time preferences, costs, and so on (Binmore et al. 1986).

Failure to acknowledge that planning is an integral part of the (evolutionary) dynamics of cities, and that its role surpasses that of regulation to enter the realm of a market player (Adams and Tiesdell 2010), can create unbalance situations in the future. Again, (evolutionary) game theory can help to reason about this type of problems. For example, by adopting a first-mover role, forming coalitions or designing different schemes for risk distribution, planning enters the evolutionary game of cities as an economically active player (Lord and O'Brien 2017). However, since planners are part of this complex adaptive system where uncertainty is paramount, unexpected results can emerge. Trust and confidence that planning creates in investors, as a first mover, can lead, in time, to risk aversion and to a reduced initiative of private investors, or it can expose planning agencies to greater financial risks when economic and financial contexts change quickly (Lord and O'Brien 2017). The role of first mover can also be fundamental in situations where the risk of investment is high, as in economically depressed urban areas where only public support to private initiatives can trigger the necessary initial change (Weiler 2016). Triggers of this type may also induce collective self-organization through imitation of successful private investors that act as first-movers. After reaching some threshold of imitators, many cities and communities witness large transformations, as it happens with gentrification or short-term rental dynamics. This type of effect portray the frequency dependence of strategies in a population of players. In some instances, the more people in a population adopt a given strategy, the more people will tend to choose this same strategy. Ultimately, the structure of the game at stake will influence the detailed frequency dependence observed.

From a theoretical perspective, these situations often translate into equilibria that are not social optimal (Camerer 2003). This may occur when changing the status quo implies the need for action that is costly (for example, by adopting greener vehicles or public transportation) (Encarnação et al. 2018). Coordination failures can also result from unbalanced socio-economic dynamics, and availability of affordable housing is just one of these examples. In this regard, let us use a Portuguese example, characterized by a combination of multi-sector and multilevel (top-down and bottom-up) interventions and conflicts and of difficult resolution for more than 40 years of planning interventions.

Illegal settlements[2] in Portugal grew considerably during the 1960 and 1970s, owing to multiple factors, including, for example, migration towards major cities and lack of affordable housing (Salgueiro 1977; Williams 1981). These settlements located primarily at the peripheries of cities, where control from authorities was easier to avoid and where land prices and construction costs were significantly lower (Salgueiro 1977). At first, this was a win-win situation for all actors involved. Sellers could initially buy rural land at cheap prices, divide it illegally and sell it at higher prices; buyers could own a piece of land and construct their own home, a scenario impossible to achieve otherwise; and the state could ignore the persistent housing shortage problem for which it had no financial capacity to respond. Perceived advantages of acquiring and building in these areas (most of them rural and not equipped for urban growth) gathered the support of a growing number of people. By the 1980s and 1990s (and even today), there was a high demand for illegal settlements, also as second homes (especially in areas located near the sea). In time, statistics on the number of people living in these areas brought to light the magnitude of the problems: non-existent basic infrastructures (water and sewer networks), green spaces and transportation, an absence of legal ownership of property and construction, and so on. The initial advantages for buyers and the state started to dwindle.

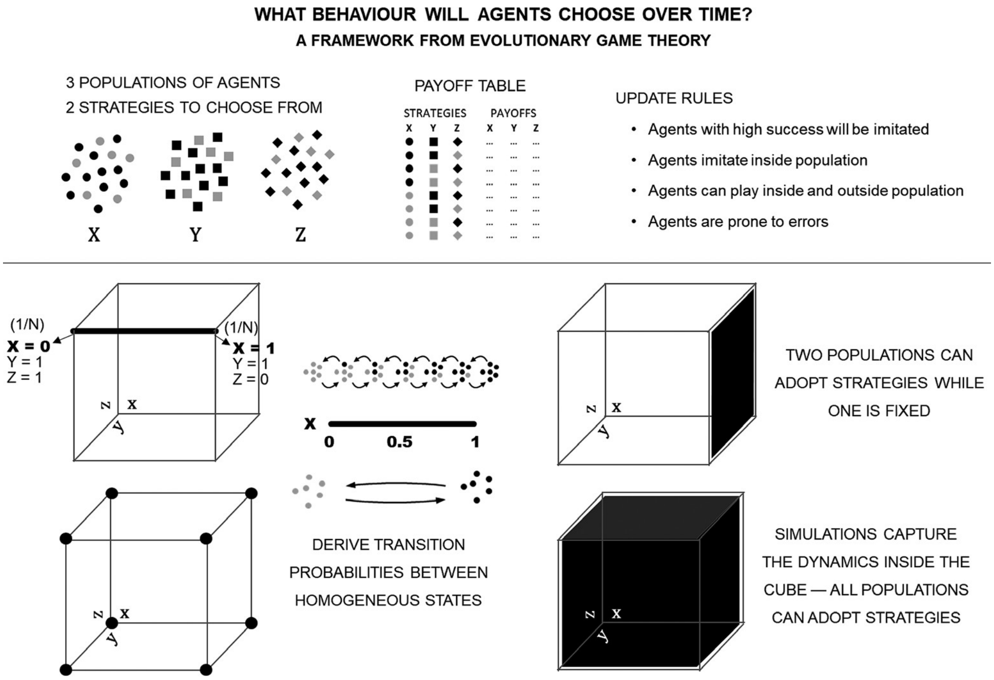
During the past 40 years, several solutions have been implemented by the central administration (Silva and Farrall 2016), creating different games with different players and mostly resorting to punishment through, for example, fines or demolitions. However, the cost of implementing punishment hindered some solutions and the lack of financial capacity hindered others. In 1995, new legislation required municipalities to integrate these areas into the municipal urban area and transferred most responsibilities to owners and their commissions of conjoint administration (responsible for receiving quotas from owners and the management of the legalization process). The consequences were not what were expected: 15 years later only 30 per cent of those areas covered by the law were successful (Ramos 2002; Raposo 2010). Legalization processes became hostage to circumstances particular to each community (for example, lack of financial resources, occupations in environmentally sensitive areas and in areas of risk). These processes were also vulnerable to free-riders owing to divergent and hidden interests among players (from the resident owner to the renter owner, both with very different local interests) (Pereira and Ramalhete 2017). Added to a lack of important mechanisms, such as mutually agreed coercion measures (Ostrom 1990), it comes as no surprise that the law was largely ineffective. Notwithstanding, the legal principle of reaching legalization through solutions that are more proximate to the population is in line with evidences showing that local bottom-up institutions can increase cooperation, when compared with global institutions (Ostrom 1990; Vasconcelos et al. 2013). The creation of a Commissions of Conjoint Administration (CCA) in each community, although theoretically positive, was flawed in practice, perhaps by not accounting for dynamics of strategic decisions between groups of people, avoiding free-riding escalation or by recognizing the importance of sanctioning measures internal to the group, and self-governance (Vasconcelos et al. 2013). Perhaps the legislation should revise how CCAs work, namely, by adapting self-sanctioning schemes. When uncertainty of results pile up in time (for example, owing to the presence of free-riders that block the process for years), evidence shows that cooperation levels tend to drop, as in other problems of collective action (Vasconcelos et al. 2015). In this regard, the design of local institutions or other mechanisms, such as public participation and collaborative planning, should take into account factors necessary to achieve higher levels of cooperation. Elinor Ostrom summarizes these as: information on past actions, small groups, face-to-face communication, costs of arriving at agreements, symmetrical interests and resources and development of shared norms – all based on paramount mechanisms such as trust, reputation and reciprocity (Ostrom et al. 1999). Planning problems such as those faced by CCAs and their communities can be understood as games with repeated encounters, where players can have information on the previous decisions of others. In these scenarios, social norms, past reputations and (indirect) reciprocity can strongly influence the dynamics of the game, but require an understanding of the complexity underlining these dynamics (Santos et al. 2017, 2018).

Evolutionary dynamics in city planning have always been the result of interdependencies between and among the multiple actors involved. However, urban planning has been slow to acknowledge and act accordingly. As theory and practice increasingly incorporate new forms of participatory and collaborative planning, the number of players from different sectors of society augments the complexity of (and the possibilities associated with) decision-making. It becomes paramount to find ways to study and comprehend how the decision of one affects the decision of others. In the next section, we review such a framework based on EGT.

4. A FRAMEWORK FOR SELF-ORGANIZING DYNAMICS IN MULTI-SECTOR SCENARIOS

In this section we show, first, how EGT changes when introducing different types of players, representing various sectors of society. Importantly, and in line with what was stated before, the planners (represented by the public sector) are part of the game. The set of mathematical and computational methods at hand to deal with these effects is wide, and some guidance may ease their application (Encarnação et al. 2016a; Santos et al. 2016). From an EGT perspective, the dynamics of the game unfold through the way strategies reproduce in populations of players. The players' success (when adopting a given strategy or behaviour) is measured by computing their average gains obtained in several different interactions with other players adopting different behaviours. Similar to the role of fitness in biological populations evolving through natural selection, here relative success will convey the capacity of behaviours and policies to reproduce in a population of city actors. Success, and thus strategy reproduction, is frequency dependent, that is, contingent on (1) how each actor and sector is performing at a given moment in time and (2) how represented they are in the total city population. The resulting dynamics and eventual equilibria can be adjusted – or in the context of the previous discussion, planned – and framed as a three-sector game (Figure 18.1, top panel).

If we assume a game between three populations (one for each sector of society), where each agent can adopt one of two strategies, we first need to define an interaction table that returns a payoff for every interaction possibility. These returns may include incentives, subsidies or taxes, applied between and within different societal sectors; may consider other parameters that enable additional policy instruments; and may also include less obvious effects, such as positive synergies, boycott or punishment (Henrich



Note: Top panel: in planning settings, X can, for example, correspond to the public sector, Y to the private and Z to the civil. Bottom panel: the cube's, vertices (associated with homogeneous states, where all individuals of each population adopt the same strategy), edges (linking transitions between homogeneous states in which only individuals from one population change strategy), faces (mixing more strategies from more populations) and interior (mixing all possible strategies) all provide information on the dynamics of the game (see text for more details).

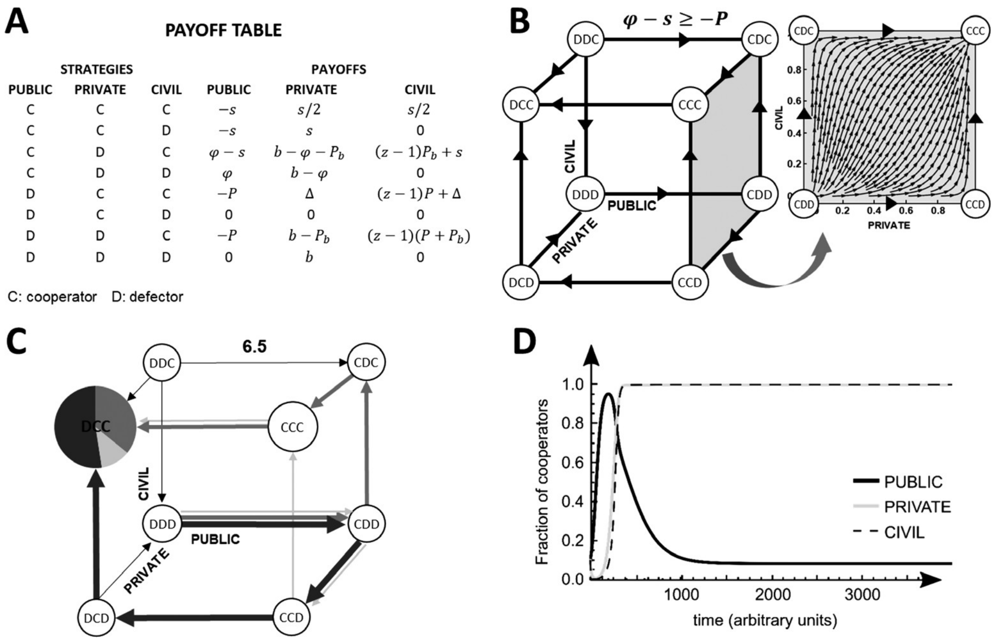
Figure 18.1 A general approach to a multi-sector evolutionary game: top panel – three-player, two-strategy game with the corresponding payoff table and game rules; bottom panel – cube representing the phase space of the population dynamics

and Boyd 2001; Sigmund et al. 2001; Stolle et al. 2005; Balabanis 2013) between sectors. The behaviour of agents will be updated following schemes of social learning principles that translate into dynamics in which more successful strategies will be more often imitated in each population (Traulsen et al. 2006; Sigmund 2010). Furthermore, agents can interact with individuals of their own, as well as with individuals of other populations (sectors); for example, when an individual in the public sector subsidizes individuals in the private or civil sector. Finally, individuals are prone to make errors. This last rule means that imitation will occur with a given probability (myopic individuals) whose degree can be adjusted via a single parameter: the higher its value, the less myopic individuals become.

It is important to note that this approach provides several advantages of interpretation, because the strategy phase space of this problem is represented by the cube representing the phase space of the population dynamics, and supported by other plotting schemes (Figure 18.1, bottom panel).[2] As stated in the note to Figure 18.1, vertices are associated with homogeneous states, that is, three-population configurations where all individuals of each population adopt the same strategy. Edges, in turn, link homogeneous states in which only individuals from one population change strategy, while the other two populations remain in their homogenous states (that is, fully adopting one or other strategy). Thus, by analysing the dynamics emerging along these edges (Imhof et al. 2005; Fudenberg and Imhof 2006; Vasconcelos et al. 2017) we provide the means to intuitively comprehend some simple features of the dynamics of cities encompassing multiple sector interactions, employing a language that facilitates a useful multidisciplinary dialogue. We can start by calculating the conditions that, on each edge, determine the most likely direction of evolution. Indeed, when each individual member adopts a different strategy, a transition occurs from one point in the cube to another, with a probability that we know how to compute (assuming a given payoff table). It is thus possible to map all the individual transition probabilities (that is, small steps along the edge, in this example) into a global transition probability between two vertices connected by one edge, which conveys how likely it is for a whole sector to transit from one strategy to the other. These global probabilities also depend on additional factors, such as the number of individuals belonging to each sector. Once individual and global probabilities are computed, one may define a (reduced) Markov chain, where states correspond to vertices and transitions to evolutionary transitions proceeding along the edges. By studying the stationary distribution associated with this stochastic Markov chain process, we may understand how likely it is for the whole population to stabilize in different configurations (in respect of strategies adopted in each sector). We are thus able to quantify the long-term outcome of the dynamics intuited by the edge conditions mentioned previously.[4] Information about the edges will also enable us to acquire the behaviour on the faces of the cube, where only one population has fixed strategies and the members of the two remaining populations can adopt an arbitrary combination of strategies. Finally, the interior of the cube depicts the rich dynamics emerging from the entire game played by the three sectors. By setting a given set of initial conditions about the fraction of adopters in each population, it is possible, numerically, to study the most likely evolution of strategy adoption when individuals from all sectors can simultaneously change their behaviour.

As an example, let us resort to a simplified version of the model developed to study the transition to more greener policies and behaviours (Encarnação et al. 2016a, 2016b), detailed in the supplementary material of that paper. As a first step we need to define a payoff table that describes the payoffs accruing to each sector, in each combination of strategies (Figure 18.2, top left).

In the table in panel A in Figure 18.2, we make use of widely used mechanisms in public policy, such as sanctions and subsidies. The state (public sector) has the capacity to grant subsidies (*s*), at a cost to itself, to both the private and civil sector (for simplicity, we gave to both sectors an equal share, but other parameters can be included to play with different shares). Sanctions can assume different forms. The state can apply fines (ϕ)[5] to private defectors, reducing their benefit (*b*) and this will enter as a positive payoff on the public sector side. The civil sector may punish (*P*) public defectors (for example, in election votes or acceptance rates) or boycott (P_b) private defectors. Although both types of punishment are costly, it is reasonable to assume that these costs will diminish as more players in the civil sector adopt the cooperation strategy (thus the factor



STRATEGIES			PAYOFFS		
PUBLIC	PRIVATE	CIVIL	PUBLIC	PRIVATE	CIVIL
C	C	C	$-s$	$s/2$	$s/2$
C	C	D	$-s$	s	0
C	D	C	$\varphi - s$	$b - \varphi - P_b$	$(z-1)P_b + s$
C	D	D	φ	$b - \varphi$	0
D	C	C	$-P$	Δ	$(z-1)P + \Delta$
D	C	D	0	0	0
D	D	C	$-P$	$b - P_b$	$(z-1)(P + P_b)$
D	D	D	0	b	0

C: cooperator D: defector

Notes:
(A) Payoff table describing the game (see text for parameters' description; the 24 entries of the table can be written in terms of six independent parameters). (B) Evolutionary dynamics along the edges of the cube and on the face of the cube (right) where the public sector is in full cooperation homogeneous configuration (shaded face in the cube). (C) Stationary distribution of the reduced Markov process, identifying where the system spends most of the time, the most probable paths and the transition probability (relative to neutral probability) of the edge DDC→CDC. (D) Trajectories form the inside of the cube shown here in respect of the time evolution for each population. See text for more details.
Model parameters: s = 0.19; φ = 0.0.66; P = 0.18; P_b = 0.16; b = 0.2; Δ = 0.19.

Figure 18.2 Simplified model for three sectors (public, private and civil) and two strategies (cooperate, C, and defection, D) game

(1 – z) in the payoff matrix). Finally, a synergistic effect between the private and the civil sectors is introduced (Δ) when both meet a public defector. Note that this game always provides for an interaction between three participants simultaneously, one from each population.

From the description of this simplified model it is evident that when the state (as the public sector) is included in the game as a player, it is possible to follow the impact of different measures on all players, including the state (Santos et al. 2016). This information can be crucial when we need to understand how, for example, financial limited capacities of a government can affect, in the long run, the outcome of a policy. Alternatively, it enables us to reason about the effectiveness of some financial effort of public finances. In Figure 18.2, panel B, arrows represent the direction of the dynamics along the edges of the cube. For each edge, we can calculate the relationship between parameters that indicates the most likely direction to take place in the corresponding edge. In the example, the system will transition from state DDC to state CDC with high probability when $\phi - s \geq P$. By also considering within-population interactions, other edges present more complex transition probabilities (for example, CDC to CDD). To complement this, we can also calculate the most probable path trajectory between the edges of the cube in order to reach the stable state in DCC (Figure 18.2, panel C). This analysis, relying on the stationary distribution of the reduced Markov process, provides a simple but powerful intuition of the full dynamics, which can always be obtained by following the time-dependence of the configurations in each population, as shown in Figure 18.2, panel D. Moreover, the stochastic nature of the Markov process dictates that, whenever two populations' configuration always obtains the same relative payoff, then there is no favourable direction of evolution, which is the social planning equivalent to neutral drift in genetics. The value of the neutral drift is trivial to calculate analytically, and is often used as the reference value for the transition probabilities along the edges; thus, the value of 6.5 of edge DDC→CDC means that the transition is 6.5 stronger than neutral drift. For the interior of the cube, where all eight possible combinations of strategies of the three populations may coexist, numerical simulations provide information about the time dependence of the configuration of each population, departing from a set of initial conditions (Figure 18.2, panel D). In the example given, and starting from 10 per cent of cooperators in each population, it is evident that cooperation in the private and civil sectors only starts when the public sector reaches its peak of cooperation. More interestingly, the model also predicts that, for these parameter values, the private and civil sectors will sustain high values of cooperation irrespective of whether the public sector remains cooperative or not. Furthermore, stationary distributions such as those shown in Figure 18.2, panel D, enable us to explore quickly the parameter space and develop an intuition of the most likely dynamics of such a complex adaptive system.

The framework presented in this section summarizes three studies that accounted for the quantitative and qualitative changes of analysing games where the role of a regulator agent is explicitly modelled as a player, as it often occurs in relationships between the state, business and society (Santos et al. 2016). More specifically, a similar approach was applied to develop an evolutionary game theoretical analysis of the possible occurrence of paradigm shifts in society (Encarnação et al. 2016a, 2016b) and of the viability of the adoption of electric vehicles (Encarnação et al. 2018). In all studies, the structure of the interaction framework remained unchanged; only the game table needed to be adapted to the specificities of each problem. In each study, the scenarios accounted for instruments such as taxes (for example, green taxes applied to different types of vehicles), subsidies to support a change in status quo, given by the public sector, but also synergies between sectors and punishment. Synergies showed that costs in one sector can be alleviated by positive dependencies with another sector, as, for example, when financial costs with subsidies in the public sector are compensated by a high approval rate from civil society. Punishment could take different forms and be adopted by different sectors. For example, punishment from the civil sector can be applied to the public sector through election votes and to the private sector through boycotts. However, this type of punishment is costly, in the same way as subsidies can be costly to the public sector and curtail its use, and sometimes can give rise to second-order free-rider problems. How to solve such problems requires future developments and new applications, such as those presented in the following, final, section.

5. FINAL REMARKS

In this chapter we started by developing a brief introduction to (evolutionary) game theory, followed by how it can shed some light on the evolutionary dynamics of cities and city planning, using several examples. It became apparent that understanding strategic decision-making, between and among agents, can positively contribute not only to planning theory but also to its practice. New forms of governance imply new roles for all agents involved, but also new forms of thinking and acting in cities. The complexity emerging from these new interactions calls for news ways to reason about them. In this regard, we presented in section 4 a framework of EGT that enables the analysis of games with three populations and two strategies. This framework can be adapted to a multitude of problems and domains. As application examples, we mentioned how this approach can be tuned to provide insights on (1) paradigm shifts towards the adoption of green products (Encarnação et al. 2016a, 2016b) and, more specifically, (2) the adoption of electric vehicles in a society dominated by combustion engines (Encarnação et al. 2018). In both domains, we show how the public sector is crucial in initiating the shift, and determine explicitly under which conditions the civil sector – reflecting the emergent reality of civil society organizations playing an active role in modern societies – may influence the decision-making processes accruing to other sectors (that is, public and private). Conceptually, however, we define different payoff tables that implement particular scenarios in each case.

Other authors use similar approaches for different applications, for example, to study incentive mechanisms to promote the transition from traditional tourism to more sustainable tourism, through an evolutionary game model that assumes players as tourists, enterprises and the local government (He et al. 2018). Authors identify key factors such as brand benefit for enterprises and green preferences of tourists. Support from local government towards brand benefit is needed especially when green preferences on the tourists' side is low, otherwise, local government intervention can be relaxed. In another study, authors treat the provision of healthcare services and patient satisfaction as an evolutionary game between public providers, private providers and patients (Alalawi et al. 2019). By resorting to the technical framework developed in Encarnação, et al. (2016a, 2016b) the authors model the evolution of cooperation between the players and measure the cost of healthcare provision. Their findings show the role patients can have by introducing punishment and reputation of healthcare providers.

To study the effect of government policies on the diffusion of electric vehicles, Li et al., apply an evolutionary approach to the underlying complex network linking the government, manufactures and consumers (Li et al. 2019). Their study analyses the impact and effectiveness of different policies in China for promoting the adoption of electric vehicles. The manufacturers' payoff in the game will be influenced by the industries' social network and this allows for surpassing the common assumption in EGT studies of using well-mixed populations. As the authors acknowledge, in reality, social systems are closely influenced by the network structure that interconnects them (Li et al. 2019) – an observation that applies to systems beyond government–manufacturer–consumer networks (Pinheiro et al. 2014), and which is often noted as an enabler of cooperation in general (Santos and Pacheco 2005; Santos et al. 2008). In this regard, the authors show that (1) the network scale of the automobile manufacturers has an important impact on the success of the diffusion process, (2) subsidies to the supply side have a higher positive effect that those on the demand side, and (3) to achieve full diffusion of electric vehicles a set of different policies and instruments is needed. More recently, Zhu et al (2020) also applied a similar approach to that introduced here, to study the strategic dynamics of individuals (belonging to the regulators and private sectors) participating in retail electricity market in China.

Ours and these more recent examples show how many instances in planning can be analysed through (evolutionary) GT as depicted in this chapter. The sheer activity and role of the decision to plan should thus be modelled beyond that of regulation and taking into account the actors it acts upon (Knaap et al. 1998). Others applied GT to study conflict between protected areas and urban expansion. They include in their model not only the conflicts between government and land developers (two-player game) but also ecological compensation mechanisms when designing zoning schemes for protected areas (Lin and Li 2016). The model was able to increase by 10 per cent the average benefit of ecological and economic benefits (Lin and Li 2016). However, planning games can also exist inside the governmental planning system and between different planning institutions, as described in one of the first works on GT and planning to study the process of town expansion in England (Batty 1977), showing how power positions and bargaining power can interfere in the process of negotiation and formation of coalitions. When the number and diversity of players in the planning stage increases, the complexity of the overall dynamics can also increase. In these types of settings, new tools become crucial not only to develop theory in planning, but also to develop new methods of planning practice. New participatory and collaborative approaches can only gain from the development of new approaches, of which GT is an integral part (Gomes et al. 2018).

Future work should accommodate other questions and challenges that planning faces. The aforementioned synergies can be difficult to interpret and model owing to the challenges imposed on quantifying and comparing them to other more directly measurable parameters. Another issue lies in integrating heterogeneous populations into models of urban planning. In this, the growing worldwide pressure of global financial players on cities is paramount. They are external players with no connection to the city or place of investment and, more often than not, the investments target is external and not the internal population that is left on the margin in the absence of interventions by players that multi-sector (evolutionary) game theoretical models can help design. Asymmetries in city games are also seen in planning issues that incorporate not only institutions from different levels (for example, central and local administration), but also institutions with different policy agendas and views (for example, political parties). Recognizing and understanding how strategic behaviour and decision-making influences evolutionary trends and dynamics of city and planning games proves paramount for future developments of planning theory, but most of all for a better adaptive and flexible planning practice.

NOTES

1. In reality, competition will continue, for example, through floor area ratios or other market dynamics, but for simplicity we do not explore that further here.

2. Illegal settlements here refer to those cases where the division, selling and buying of land for future construction did not conform to legal procedures, namely, through a municipal licence. In many instances, especially at the beginning of the phenomena, buyers were led to believe they were buying a piece of land in their own right, when instead they were just buying a quota part of a bigger land (usually not urban and without any basic infrastructure). After selling all available sites, the seller's role terminated and the process would start elsewhere.
3. We should note that different types of games define different strategy phase spaces, and thus different visualization settings. For example, the cube representation of Figure 18.1 is appropriate for a 3- population, 2-strategy (3×2) type of games. By contrast, a triangle (2-dimensional simplex) would be required for 1×3 and a pyramid (3-dimensional simplex) for 1×4 type of games. That is, the number of populations and strategies of the problem at hand determine the geometric properties of the object in use.
4. Note that this reduced Markov-chain technique greatly simplifies the overall evolutionary game theoretical analysis. As noted in Vasconcelos et al. (2017), simple extensions of the simplest formulation allow for an accurate treatment, when in instances where the dynamics along the edges entail stable coexistence states.
5. A more realistic scenario would be to include green taxes, as in the original model (Encarnação et al. 2016a, 2016b).

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