Managing complex adaptive systems: A resource/agent qualitative modelling perspective

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1. Introduction

Complex Adaptive Systems are systems where agents behave in parallel competing for control over resources in an adaptive manner. Agents have a predefined goal and are rationally bounded because of incomplete and/or biased information (Fiori 2009; Simon 2000; Simon 1972). Their behavior is subject to a condition/action (if/then) rule and goal orientation pattern (Holland 1992; Holland 2006; Gell-Mann 1997). Agents can also change their routine in order to adapt to the environment, exchanging information and/or resources. As a result of agents' nonlinear behaviour, multiplier effects can be produced. For example, complex adaptive systems such as healthcare and pharmaceuticals involve multiple subsystems of interconnected agents, resource structures and processes. They include doctors, patients, drugs and drug suppliers, hospitals and regulators multilevel interrelations that evolve and change together (Roberts 2015; Marshall, Burgos-liz, et al. 2015; Begun et al. 2003). Financial markets are another example of complex adaptive systems involving suppliers, intermediaries and buyers of financial products in a highly regulated and competitive environment (LeBaron & Tesfatsion 2008; Block et al. 2013).

Gaining a balance in such systems depends critically on resource/agent dialectical interactions. Seemingly small changes at the micro level can lead to a significant systemic misbalance at the macro level. For example, such micro level changes in housing credit regulation and extremely low interest rates in the US, coupled with a focus on short term profit led to oversupply and over demand of resources (loans and houses). This resulted in an overshoot and collapse systemic behaviour, as demonstrated in the last global financial crisis (Crotty 2009; Stiglitz 2010; Farmer et al. 2012). Another example is the recurrent inefficiencies in healthcare systems, related to inequality in access to affordable healthcare and medicinal therapies (Council of the European Union 2016; Haas-Wilson 2001; Plsek 2001), which are an outcome of inefficient regulation of the market agents behaviour, competing for acquisition and control over limited resources (within the system).

Managing complex adaptive systems can be very challenging, particularly when attempting to manage, rather than simplify, complexity (Rosenhead 2006). One particular problem is the need to take a comprehensive perspective of the complex system in order to manage it effectively (Rosenhead 2006; Ackermann 2012; Ackermann et al. 2014). Problem Structuring Methods (PSMs) have emerged out of the need to help understanding of the behaviour of complex socioeconomic systems and support structuring of key problematic issues (Mingers & Rosenhead 2004; Rosenhead & Mingers 2001; Rosenhead 2006). An overview of key PSMs can be viewed in Table I. A common approach is mapping / modelling system components and their causal interrelations in terms of influence processes, flows, feedback, and emergent properties.

Table I PSM applied in practice

PSM	Modelling technique	Focus of components	Theoretical support
Soft Systems Methodology – SSM	Rich picture (Checkland & Scholes 1999; Checkland & Winter 2006; Checkland, 1981; Checkland and Holwell, 1998),	systems resources and feedback	Systems theory (Von Bertalanffy 1968; Forrester 1961)
Strategic Options Development and Analysis – SODA	Cognitive mapping (Eden 1988; Ackermann & Eden 2010; Eden & Ackermann 2001)	statements about actions toward a goal	Cognition theory (Kelly 1995; Eden & Huff 2009; Von Foerster 2011; Mingers 1991; Huff 1990; Simon 1955; 1976)
Strategic Choice	Decision graph (Friend & Hickling 2012; Friend 2011; Friend and Hickling, 1987)	decisions about strategic actions	Ackoff design approach (Ackoff 1979)
Resource maps	Resource mapping (Kunc & Morecroft 2009; M. H. Kunc & Morecroft 2010)	resources and feedback	Resource based theory (Barney 1991; Wernerfeldt 1984); System Dynamics and Systems theory (Forrester 1987; Von Bertalanffy 1968);
Strategic Management of Stakeholders	Stakeholder mapping by Stakeholders influence network and management web (Ackermann & Eden 2011)	agents and agents' interactions	Stakeholders theory (Mitchell 1997; Carroll, 1989; Donaldson and Preston, 1995; Freeman, 1984)
Robustness Analysis	Assessing future configurations of the system (Rosenhead 2001; Rosenhead 1980)	resources configurations	Systems theory (Von Bertalanffy 1968)
Drama theory	Role "hypergame" playing for analysing conflict and cooperation (Bryant, 1997; Howard 1998)	agents and agents' actions	Game theory (Von Neumann & Morgenstern 1944; Brams 1994)
Decision Conferencing	Analysing decision alternatives (Phillips, 1987; Phillips & Phillips 1993)	decisions and actions	Decision theory (Simon 1965), Requisite modelling (Phillips, 1982, 1984)

Viable Systems Model	Cybernetic principles for viable organization (Hilder 1995; Beer 1985; Beer 1986)	resources and control	Systems theory (Von Bertalanffy 1968; Von Foerster 1979)

PSMs are inherently dialectic in relation to analysing causal interrelations. However, an important tension in systems theory is between a view of systems in terms of resource feedback structure and in terms of competing agents that adapt and change (Phelan 1999; Scholl 2001; Mingers & Brocklesby 1997).

Table I provides a summary of key PSMs applied in practice. This summary highlights that none of the existing methods integrate both resource and agent dialectical perspectives (see the column on "Focus of components") and thus are able to take account of the interactions between the components of these two competing perspectives. A comprehensive causal analysis needs to take account of the interconnectedness among resources and agents, and bring together these interdisciplinary perspectives (Eden & Ackermann 2006).

The research described in this paper provides such an interdisciplinary perspective by presenting a visual mapping technique for "cognitive enhancement" (Bryson et al. 2016) and facilitation of the dialectic between the resource-feedback and agent-based views of a system. In addition it responds to a need to borrow theory and develop procedures for the joint application of different PSMs (Ackermann et al. 2014; Howick & Ackermann 2011), which have a key role in the growing arena of "Mixing Methods" (Mingers, 2006; Howick et al., 2006; Howick and Ackermann, 2011).

This paper proposes combining enhanced Resource maps (RM) with novel Agent maps (AM) to form a hybrid Resource/Agent mapping (RAM) framework that brings together the different theoretical and practical resource-feedback and agent-based perspectives into a new PSM. Based on this purpose, the paper focuses on enhancing the RM, the design of AM, and the integration of both into a RAM framework.

This framework has the benefit and functionality of a PSM that supports gaining a "comprehensive view" (Rosenhead 2006) thereby overcoming the disadvantages of only taking a resource or agent perspective. In addition, it can be used as a procedure to support the qualitative and quantitative hybridization of system dynamics (SD) and agent based (AB) modelling and simulation approaches. This is achieved through hybrid model conceptualization and thereby also supporting model integration and validation. The framework will be of interest to modellers of complex problems for which both resources and agents are important features of the modelled complex adaptive system.

The objectives of this paper are as follows:

(i) Present an enhanced RM technique that takes a resource-feedback perspective of a complex adaptive system, adding an external resource dependence perspective to the standard RM

(ii) Present AM which is a new technique that presents an agent-based perspective of a complex adaptive system

(iii) Combine enhanced RM and AM to form a hybrid RAM that brings together both a resource-feedback and agent-based perspective to provide a more comprehensive approach to analysing complexity

(iv) Demonstrate the use of the above through its application as a PSM to an example of a pharmaceutical complex adaptive system of interacting agents and resources

In order to support the theoretical development of the RAM framework as a novel PSM, an enhanced theoretical perspective is taken that brings together Resource Dependence theory (J. Pfeffer & Salancik 1978), Resource based theory (Barney 1991; Wernerfeldt 1984; Peteraf 1993), Behavioural Decision theory (Tversky & Kahneman 1974; Kahneman 2003b) and Anticipatory Systems theory (Rosen 1985; Pezzulo 2008). The first two of these theories is used to support the development of the enhanced RM technique, and the latter two theories support the development and design of the new AM technique.

2. Theoretical framework behind enhanced Resource maps

The aim of RM is to provide a systems approach to exploring the concepts of "Resources" and "Resource" accumulation and dynamic management (Teece et al. 1997; Helfat 2011; Helfat & Peteraf 2015; Sirmon et al. 2007) from the perspective of the Resource based theory. RM is a qualitative mapping technique that has been used in relation to SD modelling and simulation practice. It applies the visual apparatus of SD through the use of stock-and-flow diagrams but is also tightly linked to cognitive mapping (Eden 1988; Bryson et al. 2016; Eden & Ackermann 1992; Ackermann & Eden 2010) with a focus on mapping managers' cognitive models regarding key strategic resources and resource-building decision making processes. RMs have been used to represent systems of asset stocks believed to be key resources for building competitive advantage and superior business performance (Kunc & Morecroft 2009; Kunc & O'Brien 2017).

RMs are informed by Resource based theory of the firm (Barney 1986; Barney 1991; Wernerfeldt 1984; Peteraf 1993) and present an internalized perspective of resource management. An example of the use of RMs is the analysis of the systems of resources and resource configurations (asset stocks) in the UK broadcasting industry that are linked to heterogeneous competitive advantage among rival companies (Kunc & Morecroft 2009). Here, 'resources' are valuable assets, internally controlled by the firm.

However, external micro and macro-economic context influence organisational behaviour. For example, when considering the perspective of agents, a key goal of market agents is to reduce environmental uncertainty and dependence on vital resources by reducing competitors' and institutions' power over them, and increasing their own power over their competitors. To take account of this external perspective of resource dependence, Resource dependence theory can be used (Pfeffer & Salancik 1978; Hillman et al. 2009) as it views the organization as an open system, dependent on contextual contingencies in the external market and regulatory environment. Resource Dependence Theory can provide an awareness of the resource depending forces and how organizations take actions to manage external resource interdependencies. Integrating Resource dependence theory with Resource based theory can provide a holistic view on resources, and may offer new insights into the organisational resource depending behaviour. This paper therefore proposes extending RMs to take account of an external resource dependence perspective.

3. Theoretical framework used to develop Agent maps

Due to its theoretical connection to the Resource based Theory and use of SD stock and flow visual apparatus, a limitation of a RM is its inability to account for market agents' behavioural decision-making. This limitation is confirmed by Phelan (1999) and Schieritz & Milling (2003), who have argued that a stock and flow diagram, i.e. a system's resource structure is static and focused on the quantity rather than the quality of resource interrelations and that an agent perspective is needed to enable quality to be modelled. In this case, quality relates to the agents' behaviour influencing changes in the level of a system's resource and in the whole resource structure. Further, Scholl (2001) and Schieritz &

Milling (2003) argue that integrating a resource flow and agent behaviour perspective could provide a means for capturing both the macro and the micro level in a complex adaptive system, and that a joint application may deliver superior results.

In order to develop an agent mapping technique, a complex adaptive systems perspective is adopted, complemented by Behavioral Decision theory and Anticipatory systems theory. Agents are described in complex adaptive systems theory as having a predefined goal and following an if/then condition action "schema" or a rule/pattern of behavior (Gell-Mann 1997; Holland 1992), which are "mental templates that define how reality is interpreted and what are appropriate response for a given stimuli" (Dooley 1996). They are rationally bounded due to incomplete and/or biased information (Fiori 2009; Simon 2000; Simon 1972) and could have a multitude of rules which can change purposefully or randomly or by combination with other schema in order to adapt to the environment. These rules can involve an exchange of information and or resources producing multiplier effects (Axtell, 2000).

An area for development in modelling agents' behavior has been identified as the application of a theoretically consistent approach to capturing agents' "cognitive structure" (Anderson 1999), or how agents take decisions. In order to be capable of mapping agent behaviour and decision making, two frameworks that can be helpful in this effort are Behavioural Decision theory and Anticipatory Systems theory. In terms of the former, Simon (1972), Kahneman and Tversky (1982) and Kahneman (2011) provide a theoretical underpinning and guidance for the development of an agent mapping technique. Market agents, whether they are individual or organizational, follow certain behavioural patterns and are rationally bounded due to incomplete information and imperfect cognition. For that reason, agents behave according to heuristic principles in order to reduce judgment and choice complexity (Tversky and Kahneman, 1974; Kahneman & Tversky 1982). These principles include "availability", "anchoring and adjustment", "representativeness" and "loss aversion" (Kahneman and Tversky, 1972; Kahneman and Tversky, 1979).

A second framework that can be useful for developing an agent mapping technique is Anticipatory systems theory in its application to organizational behaviour. In its original application to biological systems, this theory posits that anticipation is the process which enables a 'system to contain a predictive model of itself and or its environment, which allows it to change state at an instant in accordance with the model's predictions, pertaining to a latter instant' (Rosen 1985; Pezzulo 2008) and to base its course of actions on their anticipated effects (Louie 2010; Rosen 1978). Here, a limited application of the theory is proposed through the lenses of social and organisation systems behaviour. In this perspective, market agents have "payoff" anticipations and "state" anticipations, which are related to behaviourally dependent payoff and/or future states of a whole system, on which they base their optimal action selection (Butz et al. 2007).

The theories discussed above provide guidance for the development of the new agent mapping technique, which includes two stages: firstly, the design of an Agent interaction map (AiM); and secondly, the design of an Agent behaviour map (AbM). We explain their design and purpose in the following section, together with their integration with the enhanced RM into a novel RAM.

4. Developing a method for comprehensive qualitative appreciation of resource/agent behaviour: RAM

The design of an enhanced RM, AM and their integration into a RAM, focus on two key principles regarding the future of problem structuring practice (Ackermann et al. 2014) :

- borrowing theory and
- developing effective procedures for mixing methods (Ackermann et al. 2014)

As a new PSM, the development of the RAM includes the following procedures:

- Firstly, a RM enhanced by Resource Dependence Theory is developed which maps key internal and external resources, their structure, influencing factors and feedback interrelations;
- Secondly, an AM is developed, containing both
  - an AiM, which maps key agents, their interrelations, influencing factors and identifies the agents main behavioural rules;
  - and an AbM, which maps agents' behavioural condition/action pattern ("if/then" rule) in more detail than the AiM, revealing each agent's "cognitive structure" informed by Behavioural Decision Theory and Anticipatory Systems Theory;
- Finally, the enhanced RM and AM are integrated to produce a hybrid RAM;

In Table II, each of the above steps is elaborated in relation to their design principle, purpose, and theoretical support.

The way in which each map has been developed relates to their purpose and theoretical framework. In principle, the enhanced RM extends the traditional RM by including resources outside the boundary of the organisation. These additional resources are identified by determining the external resources on which its internal resource structure and performance is dependent and which the organisation cannot acquire or possess but can attempt to influence for their own benefit. An enhanced RM therefore looks the same as a RM but with the addition of external resources. For example, internal resources for pharmaceutical companies include resources which the firm can possess, and control, such as production volume supplied, product market price, product patents. However, external resources are resources that they cannot possess, but are dependent on, such as doctors and their prescribing behaviour, dispensing pharmacists and treated patients, government regulation, parallel traders and public price, rival production volume and price. Also, public budgetary resources affect the spending behaviour of health care providers, on which pharmaceutical companies depend. This spending behaviour is also impacted by health care regulation of drug prices and agent interrelations on the market. Pfeffer and Salanchik (1978) regard government as a key stakeholder and government regulation as an important external resource on which economic actors' activities depend, and which economic agents are trying to control or shape (Hillman, 2009).

The purpose of AiM is to capture: (i) the key agents (for example drug firms and health regulators), (ii) their actions, through behavioural rules, in relation to the analysed problem situation (for example rules with respect to production, pricing, supply and marketing), (iii) how their behavioural rules interact, and (iv) which important conditional factors influence the agent behavioural rules. In summary, the AiM defines the key agent rules and their interconnections.

The purpose of the AbM is to depict, in more detail, each agent's behavioural rule identified in the AiM. Its focus is on revealing each agent's decision structure. It identifies for each agents' action, which decision depends on which condition. This is informed firstly by the Behavioural Decision Theory in relation to the behavioural heuristics guiding agents' condition action (if/then) routines, and secondly by Anticipatory Systems Theory in relation to agents' forward looking behavioural motivation, connected to their anticipated goals (payoff) and future system states. Agents' behaviour exhibited in the AbM is not intended to make predictions but instead to consider what action the agent would take if a certain circumstance occurred.

The enhanced RM, AiM and AbM are then integrated into a hybrid RAM, which aims to present how the different agent rules influence resource levels through their point of interaction with key variables and resource flows, i.e. through their "decision points".

Mapping approach	Design purpose	Theory
I. Enhanced RM	○ Extends the RM approach (Kunc & Morecroft 2009) based on a Resource based Theory perspective of the firm, enhanced by the Resource Dependence Theory ○ mapping key internal and external market resources, in relation to the firms' boundary, influencing factors and variables and eliciting feedback interrelations ○ Analysis of resource structure and feedback dynamic relations	Resource based Theory (Barney 1991; Wernerfeldt 1984; Peteraf 1993) Resource Dependence Theory (Jeffrey Pfeffer & Salancik 1978; Hillman et al. 2009)
II. AiM	○ Mapping agent interactions, building upon the Stakeholders Management mapping concept (Ackermann & Eden 2011) ○ Identifies each agent's key behavioural decision rules and key influencing factors ○ Analysis of agents' structure and influencing dynamics	Behavioural Decision Theory (Kahneman 2003b; Kahneman 2003a; Kahneman & Tversky 1982; Gigerenzer 2000; Kahneman & Tversky 1979)
III. AbM	○ Mapping each agent's behavioural decision rule (cognitive structure) in more detail through an agent behavioural rule matrix ○ Analysis of agent decision rules and behaviour	Behavioural Decision Theory (Kahneman 2003a; Kahneman & Tversky 1982); Anticipatory Systems Theory (Louie 2010; Pezzulo 2008; Rosen 1985)
IV. RAM	○ Integrating Enhanced RM and AM (AiM and AbM) into a hybrid RAM ○ Analysis of resource/agent interactive behaviour and identification of scenarios emerging out of variations in resource and structure, agent behavioural rules and contextual factors	Integrating Systems with Complex Adaptive Systems theories (Phelan 1999; Schieritz & Milling 2003; Guerrero et al. 2016; Borshchev & Filippov 2004)

Table II Theoretical support for RAM development

In the next section, we illustrate how enhanced RMs, AiMs, AbMs and RAMs are developed by their application to the qualitative analysis of the effect of the pharmaceutical external reference pricing (ERP) regulation on equitable access, affordability and availability of medicines. The purpose of the ERP study is to provide an illustration, and further insights into, the design and application of the enhanced RM, AiM and AbM.

Pharmaceutical and health care systems are appropriate systems for application of the RAM approach, as they are complex adaptive systems of interacting agents and resources (Roberts 2015; Marshall, Burgos-Liz, et al. 2015; Begun et al. 2003; Djanatliev et al. 2015) . Both the resources and agents, and their relationships change over time maintaining "complex systems of changing problems that interact with each other ..." (Ackoff 1979). Our aim is to show how RAM can help decision makers achieve a comprehensive evaluation of the effect of complex health care interventions, such as pricing regulation in the EU, including generating management scenarios for optimal system regulation.

This example is presented using the graphical apparatus of Anylogic software (Anylogic 8.4.0 University). Anylogic has been chosen for its capability of developing hybrid SD and AB modelling and simulation, and for its graphical user interface, allowing for both qualitative and quantitative procedural integration. This also allows the qualitative RAM to be further developed into a hybrid quantitative simulation model using the RAM framework, which will be the focus of a future paper.

5. The External Reference Pricing case study

The ERP is a pan European regulatory practice. It is applied by national authorities to benchmark a medicine price among a "basket" of EU member markets. It is controversial in relation to its effect on medicine access, affordability and availability (Leopold et al. 2012; Carone et al. 2012; Vogler, Zimmermann, et al. 2015) and contains important challenges such as the price calculation formula and reference countries choice, variation in implementation among applying countries and existence of confidential pricing (Schneider 2017).

The rationale of the ERP is connected to the containment of pharmaceutical expenditure and to a governmental need to regulate the price in pharmaceutical markets, due to information imperfection. With respect to pricing, health authorities believe that "if left unregulated can lead to market failure" (Schneider 2017), such as drug unavailability, delay or unaffordability. The next five sections of the paper describe how the enhanced RM, the novel AM technique and the integrated RAM are used to analyse the effect of the ERP regulation on drug market timely access, drug price affordability and drug availability, in accordance with the European Council report on sustainability of pharmaceutical systems in the European Union (Council of the European Union 2016) .

6. Data collection and validation

Information regarding the ERP context was collected through written documentation output such as the EURIPID report (Schneider 2017), pharmaceutical industry position letters, author observation and participation in drug industry working group meetings and meetings with health care regulatory authorities. The goal was to use the data collected from document analysis (Barr et al. 1992), minutes of meetings and industry position papers (Huff & Schwenk 1990; Barr et al., 1992), conversations, researcher notes and reflection (Ackermann 2012; Ackermann & Eden 2011; Eden & Ackermann 2004), for the mapping of mental models (Doyle & Ford 1998; Carley 1997; Jones et al. 2011) of key stakeholders in the pharmaceutical market, i.e. the pharmaceutical industry and drug pricing regulators.

To extract relevant information, the authors used a theory led thematic analysis (Hayes 1997) protocol, consisting of looking for, and elucidating, meaning connected to the following themes:

- Key resources and key agents in the pharmaceutical market system;
- ERP regulation effect on the pharmaceutical market system, in relation to drug access, affordability and availability;
- Key agent/resources and agent/agents interrelations, including the main influencing factors affecting resource levels and flow rates and agent behavioural routines;
- Key agents and resources behaviour in relation to ERP regulation and other contextual pricing and market regulation;
- Agents behavioural routines (agents' "if/then" condition action rules), in relation to the effect of ERP on their pricing strategies

The main information sources are shown in Table I in Appendix I. The information extracted from these sources was categorized in two further tables (Table II and Table III shown in Appendix I), which describe the key resources and agents identified in addition to their related influencing factors. This information was used to guide the creation of the enhanced RM, AiM, AbM and the hybrid RAM.

Validation of the maps involved the following procedure. Firstly, when building the maps the content of each map (resources, agents, agents' rules and interconnections) were an "understandable and tight description of how the "world" works" (Howick et al. 2008) since they come from documented stakeholders' statements related to the above concepts and to the functioning of the ERP regulation in relation to its effect on drug access, affordability and availability in EU.

Secondly, documented stakeholders' statements (innovative and generic drug companies, health care regulators, drug pricing experts) were taken to be valid representations of their mental model (understanding) about the above, since they are used in official position papers, meeting minutes and journal publications (Huff & Jenkins 2002; Carley 1997).

Thirdly, the maps and generated scenarios were presented to stakeholders' representatives and independent experts in the ERP drug pricing regulation and pharmaceutical markets (Eden & Ackermann 2004; Howick et al. 2008). Validation of the maps followed a conversation approach for ensuring "legitimacy and rightness" (Franco, 2006) in relation to gaining agreement (Mingers and Rosenhead, 2004) on the representation of the maps' interconnected elements The conversation was conducted through semi-structured interviews that focused on key resources, agent behavioural rules and their interrelations.

7. Application of enhanced RM

An enhanced RM is presented in Figure II. It provides a qualitative model of the ERP system conceptualised through the perspectives of both the Resource based Theory and Resource Dependence Theory and using the graphical apparatus of traditional SD (Morecroft 1999; Kunc & Morecroft 2009; Kunc & O'Brien 2017). The enhanced RM included resource dependence perspectives and was built from the collected information that was discussed in the previous section. Building the enhanced RM required elicitation of key feedback loops responsible for the endogenous dynamics of the ERP system. This involved mapping the main internal and external resources and resource flows identified through the collected data described in Appendix I. The map included key influencing factors on drug resources and drug prices, the interrelations between influencing factors, resource flows and resource levels. Arrows were used to denote the direction of influence/interdependence. When the map was completed, the pharmaceutical ERP system structure was differentiated by three different coloured interconnected substructures: Innovative drug market, Market with generic drug competition, and Parallel trade market. Figure II shows that these substructures have a separate and combined influence on the ERP system in relation to resource levels and agents' behaviour.

The next phase of the mapping process included identification of important reinforcing (R) and balancing (B) feedback loops, which provide the nonlinear dynamic state of the pharmaceutical market system. These loops were elicited by examination of the interconnections among the system resources. A key variable in the market is the product price (the officially approved price and the actual one used in the retail market). The higher the officially approved external reference price of a medicine (the ERP price) in a reference country, the higher the product public price in the referenced country (loop R1) and the higher the capability for drug supply (volume), related to agents' decisions to supply (either under patent or off-patent), which is evident in loop R2. However, this reinforcing feedback loop could also mean that all variables in this loop decrease over time, if the reference price starts to decrease.

The higher the impact that the ERP regulation ("ERPEffect") has in one country on price lowering, the lower the level of the official public drug price ("DrugPubPrice") (loop R1). In turn, there would be a lower willingness to supply ("DecisionSupply") the drug in certain countries for economic reasons, avoiding circular price benchmarking among reference countries (loop R2). Maintaining a higher market price per manufacturer would result in a higher profit margin, which would increase manufacturing and supply. In turn, companies could relax the retail price in a monopolistic market, giving larger discount to the public payers (loop B1). In addition, a higher market price would decrease drug consumption in an off patent market, which would produce competitive pressure on price discounting, leading to a decrease in market price (loop B2). Another important factor on the market is the level of parallel trade (buying the imported medicine from a lower priced national market and re-exporting it to an EU country with a higher price) which would affect the local market drug volume negatively through reduced availability and could facilitate a decision not to supply to that local market (loop B3). However, market competition (supply of the same drug by rival companies) could offset the availability problem, either with or without a delay. The degree of market competition would be higher with the higher number of suppliers (generic medicine manufacturers) entering the off-patent market, and would generate higher demand through an increase in incentivising activity and doctor prescriptions (loop R3).

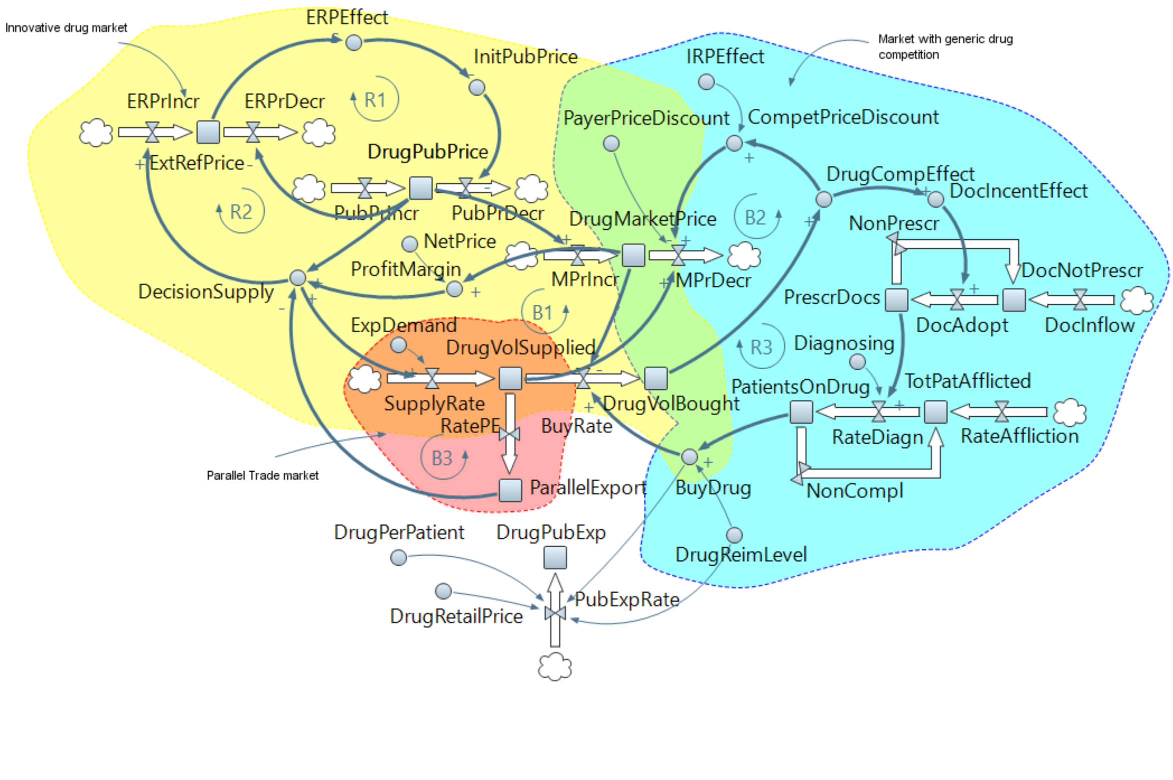


Figure II. Enhanced RM of the ERP effect on the pharmaceutical market

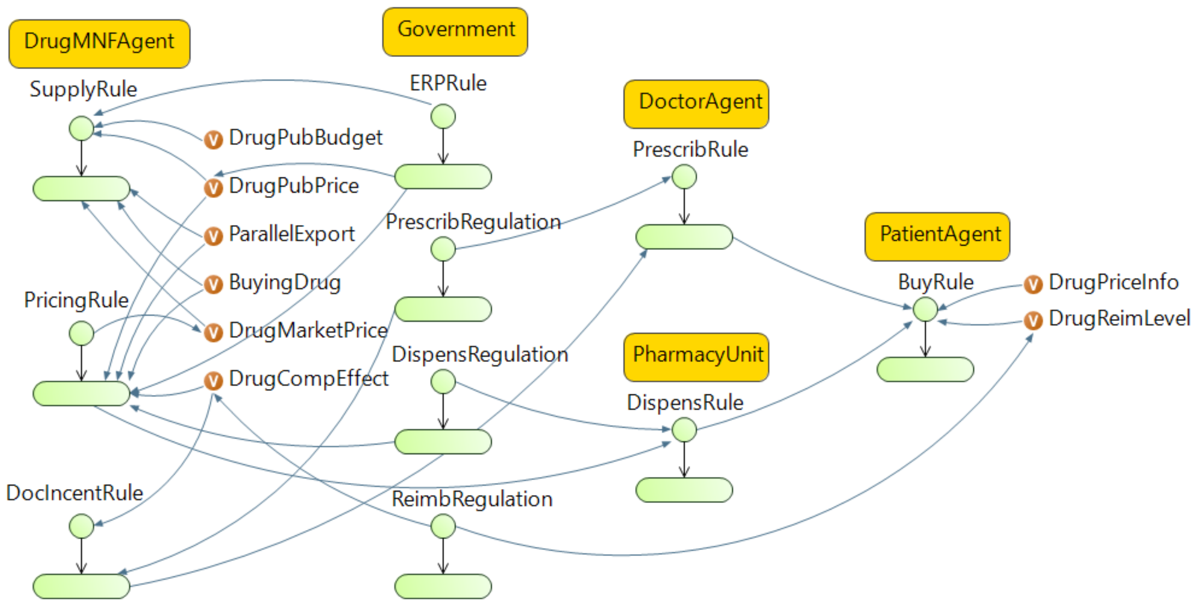
The prime purpose and benefit of the enhanced RM relates to the visual depiction and elicitation of the key internal and external resources, structures and feedback interrelations. This has been shown through exploring of the effect of the ERP regulation on the pharmaceutical market system regarding access, affordability, and availability of medicinal products. The enhanced RM can be used as a problem structuring technique; however, the RM does not take account of agents' influence on resources. This will be considered in the next section which explains the AM technique and the integration of the enhanced RM and AM into a hybrid RAM.

8. Application of AM

The AM approach consists of two mapping techniques: AiM and AbM. An AiM of the pharmaceutical market is provided on Figure III. Its purpose is to identify the main agents, their behaviour rules and the interrelations between them and the main market resources and influential factors. The key market agents influence each other's behaviour by interacting with each other within the constraints of the market environment and regulation. Manufacturers are influenced by Pricing and Reimbursement, and Prescribing and Dispensing regulation including a drug's public price, which is constrained by the government's health budget. Doctors and Pharmacists are influenced by companies and government incentives. Patients are influenced by Doctors and Pharmacists and by the level of information they have regarding the price of medicines. The AiM on Figure III describes how the drug manufacturing (MNF) agent follows three main condition/action rules represented by a symbol for a decision chart borrowed from the Anylogic software graphical palette: an Agent Supply Rule, a Market Pricing Rule and a Doctor Incentivising Rule. The first two of these are analysed in more detail by the AbM in Figure IV, where the decision rule symbol is further detailed in a decision sequence chart. It is worth noting that there is no meaning associated with the individual circle or oval contained in the decision chart symbol, they are taken together as one symbol. The purpose of this compound symbol is to denote a transition from condition to action, thereby representing an agent behavioural rule.

The Agent Supply Rule is affected not only by the ERP government rule controlling the public price of the medicines, but also by a number of market factors such as; the limited allocated public drug budget for which agents compete, drug demand, market price competition and the actual price of a drug. Prescribing regulation influences doctors' prescribing patterns and doctors' incentivising rules, which further influence the doctors' prescribing rule through brand incentivising activity. Dispensing regulation influences pharmacy dispensing rules and drug agent market pricing rules, which in turn influence further dispensing patterns by product price discounting. Reimbursement regulation influences market pricing rules through drug market price competition and patient buying rules, through the level of reimbursement and patient co-payment.

The agent interaction map reveals not only who influences who, but also which agent behavioural rule influences other agent's rules. The ERP rule effect on drug manufacturing agent behaviour is imposed directly on agent decisions to supply through drug public price setting and indirectly on agent market pricing rules through the market price discount. Furthermore, a pharmaceutical firm's supply and market pricing rules are influenced by key market factors and resources such as drug demand, the public budget for a drug, market price competition and parallel export/import. Some of these factors are represented as resource stocks in the enhanced RM and in the hybrid RAM, such as drug volume bought ("DrugVolBought"), parallel export ("ParallelExport"), public price ("DrugPubPrice"). Market Agents, individual or organisational, follow a behavioural pattern determining what action they take at any time and after what rule. This is informed by their perception of the environment and optimal decision making. Agents can change their behavioural pattern prospectively or reactively in order to adapt to the changing environment.



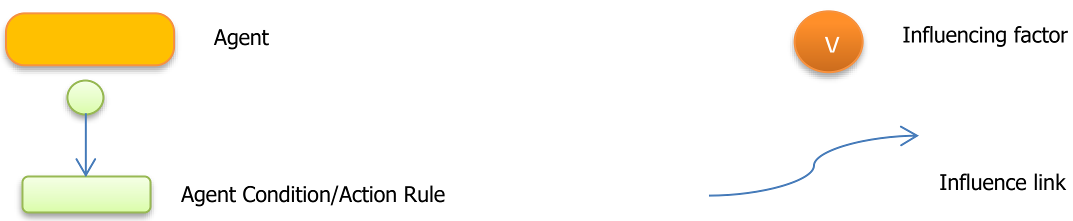


Figure III. AiM of the pharmaceutical market

It should be noted that the innovative companies and generic drug companies listed in Table III in the Appendix have been combined into one drug company agent (DrugMNFAgent) in Figure III to help simplify the figure.

Information on agent-behaviour routines (agents' condition action rules) emerged from documented stakeholders' statements and analysis of the AiM. Examples of such statements are given below, taken from official positions of the European Federation of Pharmaceutical Innovative Associations (EFPIA) and European Generic Medicines Association (EGA, now Medicines for Europe), included in the European Commission report on External reference pricing (Toumi, M. et al., 2014):

- "ERP and parallel trade created spill-over effects from low price to higher price countries leading to patient access issues in low price markets" (EFPIA position);
- "Referencing prices in countries where procurement and tendering systems are in place (driving down the prices to unsustainable levels) would be detrimental for the generic sector, for patients (availability of affordable generic medicines) and for payers (savings for the national health systems)" (EGA position);
- "ERP becomes an incentive for pharmaceutical companies to adopt international pricing strategies. The "launch sequence strategy" is used to delay or avoid launching new drugs in countries with lower prices, especially if these are small markets referenced by countries with larger markets." (Toumi, M. et al., 2014);

It should be noted that conditions that can initiate agent actions differ from environmental factors (which are variables and resources) and their general influences.

Conditions for actions are associated with the values of a factor that can have a threshold effect ("go or no go") on competing agents' actions, thus forming agents' routines. They are also related to the agents forward looking behaviour, associated with agent's performance goals (payoff) and to the agent's expected organisation's future state. Pharmaceutical agents' routine, related to drug supply and drug pricing is presented in Figure IV as a matrix of interlinked anticipated goals, heuristics, and conditions/actions, forming an agent behaviour map. The AbM depicts each decision/action routine for a chosen agent based on the AiM. The depiction of agents' behaviour, i.e. their decision/action routines was based on the collected data and followed a theoretically consistent framework protocol, explained in Table II.

The AbM is a matrix that presents the sequence of agent condition/actions, based on agent anticipated goals, guided by the agent's main behavioural heuristic and decision system. The mapping starts from the top of the matrix using short phrases, linked by unidirectional arrows that provide a description of the agent's anticipated goal, the agent decision heuristic, the agent's actions, and related conditions for each action. The arrows are labelled "A" for action and "C" for condition. The agent behaviour rules are mapped on the left-hand side of the matrix. On the right-hand side, the decision/action routine is aligned to the goal, heuristic, condition/action, and decision system protocol.

The AbM displays the agents' actions and conditions on which they depend, forming a connected representation of the agents' behavioural routine, thereby supporting qualitative analysis of the agents' 'cognitive structure' (Anderson, 1999). This analysis is enabled by both the Behaviour Decision theory and Anticipatory Systems theory. In accordance with these theories the AbM relates condition and actions to the relevant agent behavioral heuristics and payoff or future state anticipation, (i.e., agents' responses to 'what if' changes in the system).

With respect to drug firms, they have a predefined payoff goal of optimal economic return and their actions are guided by the principle heuristics of 'Anchor and adjustment' and 'Loss aversion'. The drug firm behavioural routine, displayed on the AbM, can be transformed into a more formal IF THEN protocol or algorithm.

The drug manufacturing AbM in Figure IV provides insight into the behavioural routine of the pharmaceutical agents, in response to the ERP regulation applied around the EU. The sources of agents' actions and conditions included in the AbM are from the information collected through document analysis which is explained in section 6 and in Appendix I.

Drug manufacturing agents have an anticipated payoff (Butz & Pezzulo 2008; Pezzulo & Castelfranchi 2009; Axelrod 1976) or economic return on investment in R&D, attached to any product launch, in the form of a planned profit margin percentage ratio. Agents will set a minimum percentage ratio, which they would not go below. Their price decision making is driven by the dominant logic of the market (Prahalad & Bettis 1986; Helfat & Peteraf 2015), following anchoring and adjustment and loss aversion behavioural heuristics (Kahneman & Tversky 1982; Schwenk 1984; Simon 2000; Simon & Feldman 1959).

The anchoring and adjustment principle related behaviour is translated into a sequential product launching activity in the EU country markets, "anchoring" the local price in high GDP countries, which can support higher price setting than other countries. It then "adjusts" the public and market price through mandatory or nondisclosed price negotiation with local payers, and further through competitive discounting (Carone et al. 2012; Leopold et al. 2012; Schneider 2017). Furthermore, the above price setting heuristic allows pricing of the product at an optimal level and exploits an upward feedback pricing effect through the ERP regulation.

The loss aversion principle behaviour is represented through avoiding the ERP feedback effect, which leads to price reduction in the referenced country. Agents can avoid the ERP feedback effects by maintaining a higher local public price, competing on price discounting. This can also be achieved by withdrawing a product from a local market, on the condition that the ERP feedback effect (through price benchmarking) could lead to unaccepted public price reduction in the referenced country, and then to a spill over effect in other cross referenced country markets (among the countries in one reference price basket). Agents can re-enter the market if there is no ERP effect or if there is an appropriate change in the pricing regulation offsetting the above effect.

The mapped agent activity pattern contained in the AbM aims to unveil the pharmaceutical firm's ERP related behaviour and their condition/action dependence. The map can also inform a quantitative model coding process through the links between agent behaviour and the rules and conditions it will be dependent on.

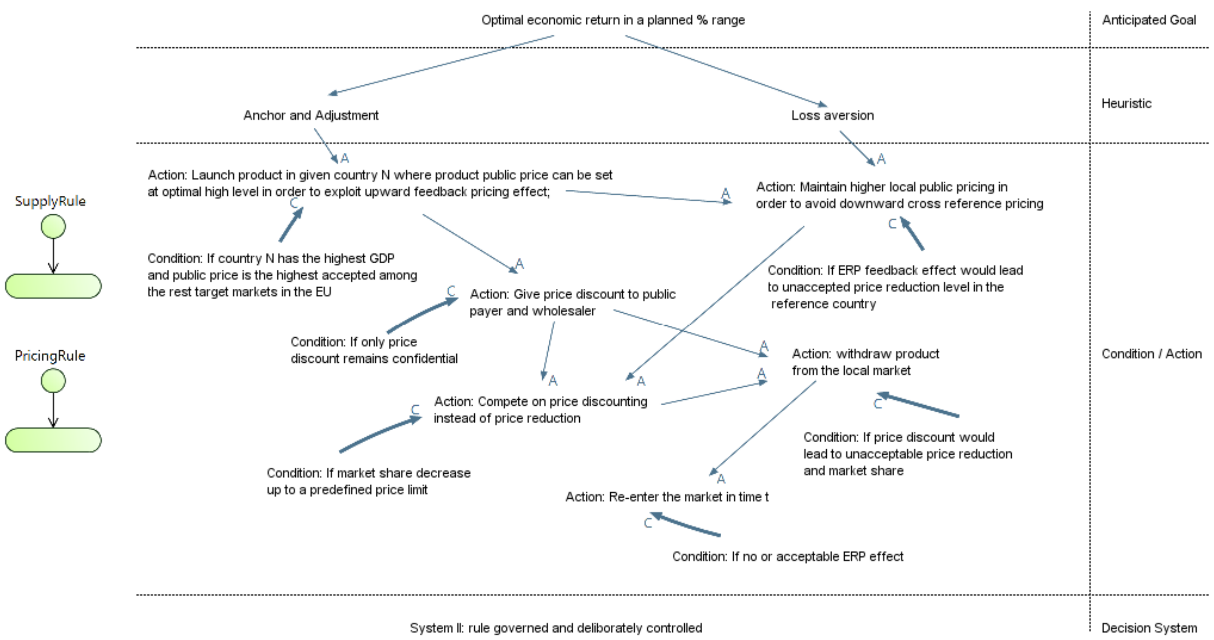


Figure IV. Agent behaviour map of the agents' condition action routine

9. Integrating Resource/Agent mapping to create a hybrid RAM

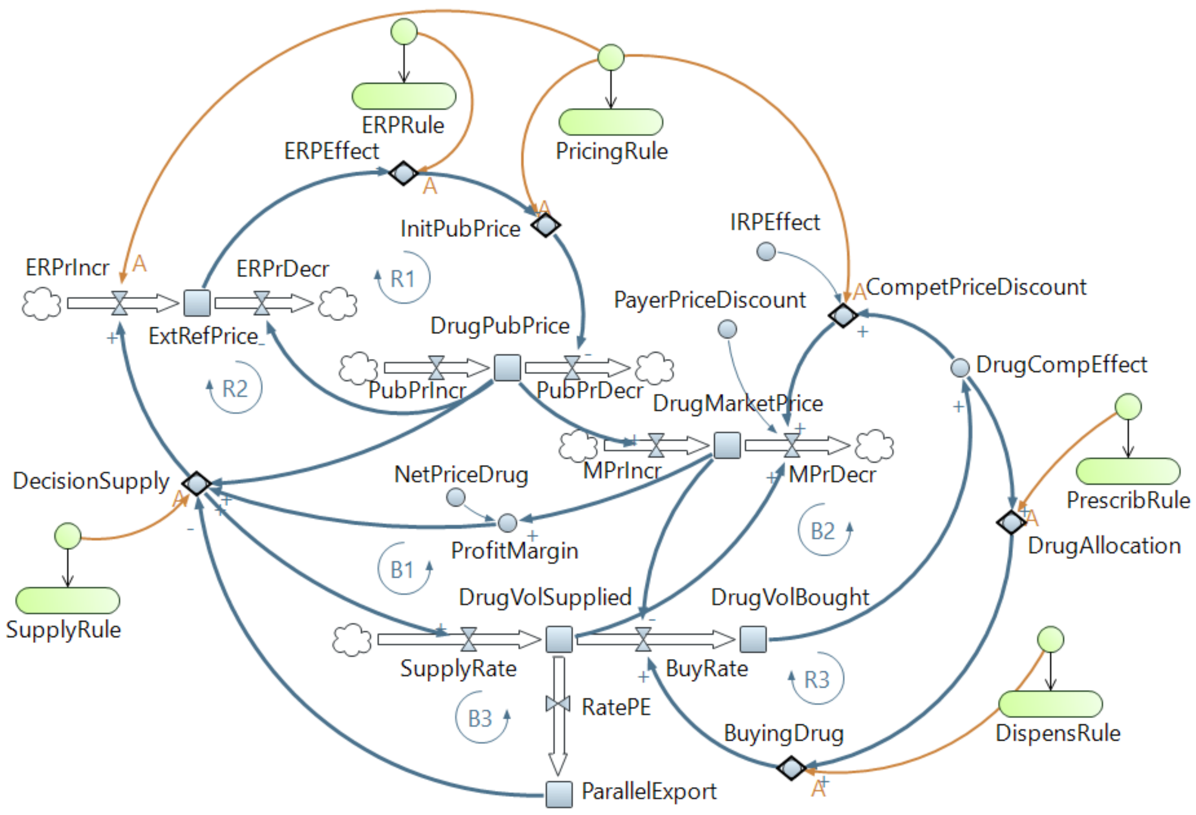
The enhanced RM and AMs were integrated (see Figure V), with the aim of highlighting the main interdependencies among key market agents and market resources in relation to the ERP effect on the pharmaceutical market dynamics. The hybrid RAM analysis presents a rich cognitive model of the pharmaceutical market. The market can be seen to be driven by a number of important feedback loops and agents forward looking behavioural decision making routines, exhibiting the supply and demand dynamics on a pharmaceutical country market with or without competition (an off-patent or on-patent market). Integrating RM and AM supports a comprehensive hybrid exploration of the complex interrelations among market agents and market resources. The hybrid RAM can also be used to become a blueprint for the integration of SD and AB qualitative and quantitative modelling methodological frameworks, through the identification of the effect of the agent decision/action routine on the resource system evolution.

The enhanced RM and novel AM were integrated into a RAM, using the following process:

1. The RM was changed by replacing resource stocks for doctors and patients with their corresponding agent rules. Doctors and patients were initially treated in the RM from a resource perspective, but including an agent

perspective requires changing them from passive stocks of resources to become active agents. This is achieved by connecting their condition action rules to their decision points at the variables "DrugAllocation" and "BuyingDrug" respectively. All key resources, variables, inflows, outflows, and feedback loops in the modelled system were kept with the influence arrows network realigned in accordance with the above.

2. The key agents' rules included in the AiM, and explained in the AbM, were connected to their relevant decision points, which are identified in the analysis of the agent maps and when combining them with the enhanced RM to form a RAM. They are connected using unidirectional arrows and denoting the "decision points" by the UML sign for a decision branch (a diamond shape).
3. The arrows connecting the agents' rules with their decision points on the RM have been labelled using the letter "A" for "action". This notation has been taken from the AbM.



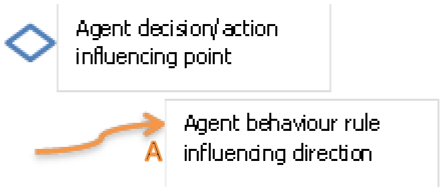


Figure V. Hybrid RAM example, related to the main agents' condition/action behavior and their rules: drug manufacturer and government

The RAM in Figure V presents the interactions between key agents decisions and resources, related to the ERP example. For this reason, the RAM provides analytical capabilities beyond a standard SD stock and flow diagram, which focuses only on resources without considering agents' behaviour. Not all agent rules identified in Figure III are shown in the presented example for comprehensibility reasons. The RAM aims to elicit the influence of the market agents upon the pharmaceutical system resource structure through their decision/action routine, and to identify the agent/resource decision interaction points. Also, the influence of resources on agent behaviour can be analysed by tracing the arrows from resources to the agent resource interaction points. An agent's decision to supply ("SupplyRule") influences the level of drug volume supplied ("DrugVolSupplied") and the level of external reference price ("ExtRefPrice"), thereby controlling product price and availability on a given local country market. In turn, an agent's decision to supply is influenced by the drug public price level ("DrugPubPrice"), the drug market price ("DrugMarketPrice"), and the level of parallel export ("ParallelExport"). In addition, an agent's pricing rule ("PricingRule") influences the drug public price level ("DrugPubPrice") and is influenced by the external reference price regulation effect ("ERPEffect") of the "ExtRefPrice". An agents pricing rule can also be influenced by the drug volume bought resource, through the drug competition effect.

It should be noted that some direct links in Figure III have transformed into indirect links in Figure V. The reason for this is that the connections between variables in the AiM only consider agent to agent interrelations, while the connections in the RAM need to take account of agent to resource and resource to agent interrelations. For example, the direct link between the 'ERPRule' and 'SupplyRule' in the AiM has been transformed into an indirect link in the RAM (through the links to 'ERPEffect', 'InitPubPrice', 'DrugPubPrice', 'Decision Supply').

Decision points in the RAM represent a link point between an agent behavioural rule and a given variable, influencing a resource level. These are denoted on the map by the use of an UML graphical symbol for a decision branch to support visual comprehension of the key turning points in the resource structure, emerging out of agents' activity. The RAM is conceptualised not as a mechanical overlaying of the enhanced RM and AM, but as an integrated map, which can provide understanding of the endogenous dynamic interdependence among agent decisions and the level of resources transforming the market system into a system of agent/resource interactive configurations. Using the hybrid RAM, turning points of the pharmaceutical market system were found, where agents' condition/action rules, that form their behavioural routine, could influence the resource system behaviour in counterintuitive and nonobvious directions. For example, the drug manufacturer agent rules related to drug supply, drug pricing and doctor incentivising, could compete against the ERP purpose of reducing prices, by turning the intended ERP effect of a price decreasing feedback loop into a price increasing loop, through a product launch sequencing tactic around EU country markets, initialising an optimal higher price, and competing on nonpublic discounting and prescription incentivising (evident in the RAM at loop R1, loop R2 and loop B2).

It should be acknowledged that, due to space restrictions, the RAM presented on Figure V is a generalized illustration for a local country market. This means that the agent decision rules described in detail in the AbM are not exhibited in the RAM within each symbol used for an agent rule. For this reason, the RAM presented in this article should be used in conjunction with the AMs for a comprehensive analysis and identification of key turning points. When producing a full RAM all agent and resource components and interconnections from the AiM and AbM should be presented in one place.

Insights for a decision maker that can be taken from analysis of the RAM, related to the ERP effect on equitable drug access, availability, and affordability on a national and EU wide level are as follows:

- Access: A drug supplier agent could delay entry of a medicinal product in one EU country compared to another, due to an ERP counter effect avoidance (refer to loop R2) or parallel trade agent competition avoidance (refer to loop B3 companies avoiding circular price referencing through sequential launching);
- Availability: A medicinal product could become temporarily unavailable in one EU country, due to a parallel trade agent exportation effect (refer to loop B3) or due to

an ERP induced strategic withdrawal by the drug supplying agent (refer to loop R2, this could be a market tactic to exit and re-enter with a higher price and not to interfere with another country's ERP regulation), or due to competition between drug supplying agents (refer to loop B2);

- Affordability: A product could have a low affordability level (having high reimbursement or high out-of-pocket value) by drug supplying agents maintaining higher public price and higher market price for longer than they would have been capable of if there were no ERP regulation, in order to generate an upward pricing effect through a wider ERP application (refer to loop R2 and loop R1);

The above analysis was supported by the RAM through exploring the possible effect of the agents' condition/action routines on the reinforcing or balancing loops, through their influence on the key turning points in the RAM. Being able to "see the whole" complexity of the ERP effect through the application of the hybrid RAM leads to advantages pointed out by Ackermann (2012) such as "(a) ensuring the situation is explored from a range of perspectives, (b) widening the number of alternatives generated and (c) enabling new options to emerge".

10. Scenario identification with RAM

Using the RAM, eight hypothetical scenario cases, related to the ERP effect on the pharmaceutical market were identified (Table III). In general, a RAM can be used to identify and explore system scenarios based on the following three aspects:

I. Variations in the resource structure of the system. For the ERP example, this was monopolistic (considering the RAM without the effects of competition presented in loop B1, loop B2 and loop R3) or with competition (considering the RAM with competition effects contained in each loop above through "CompetPriceDiscount" and "DrugCompEffect"), or with or without parallel trade (considering the effects exhibited in loop B3.

II. Variations in the agent behaviour rules that influence resources. For the ERP example, these are the external reference pricing rules imposed by the government (considering the effects of "ERPEffect" and "DecisionSupply" in loop R1 and loop R2).

III. Contextually related variations related to agent and resource interactions in order to analyse their impact on the agent rule and resource system evolution. For the ERP example, this includes local differences in prescribing ("DrugAllocation" and loop R3), dispensing ("BuyingDrug" and loop R3) and reimbursement ("IRPEffect" and loop B2) regulation.

It is worth noting that the scenarios can also be used for simulation 'what if' experimentation if a quantitative model was developed.

To provide examples of the insights that are gained from the identified scenarios, the first four scenarios in Table III are now described. All scenarios have been discussed with independent experts, who confirmed their possibility for the pharmaceutical markets in the EU.

Scenario I explores the ERP regulation effect on a monopolistic drug market, i.e. a drugs market under patent protection. Under such a market, companies can delay product entry into less attractive countries in terms of local ERP pricing regulation and its anticipated effect. For example, if there are local mandatory price discounts for reimbursement that could have price decreasing feedback (or a spill over effect) through the ERP mechanism, such countries might experience a delay in product entry. This effect will hinder equitable access to drug therapy in EU. The effect of ERP on drug affordability for patients would be zero due to the full reimbursement of patented drugs by the healthcare funds.

Table III. Scenario analysis of the integrated RAM

Scenario title	Scenario insight
I. ERP in monopolistic market (only patented drugs)	ERP effect on access: no or little delay in product entry; ERP effect on affordability: no effect if reimbursement is full but high effect on the public budget resources; ERP effect on availability: no effect on drug exit;
II. ERP in market with competition (patent and off patent)	ERP effect on access: delay in product entry; ERP effect on affordability: no effect if reimbursement is full; the lower the reimbursement the lower the affordability, i.e. the higher the copayment; ERP effect on availability: effect on drug exit, if price competition is too intensive and ERP cross reference loop could lead to downward price convergence;
III. ERP with Parallel Export	ERP effect with Parallel export like the above, i.e. Parallel export does not interfere with ERP regulation;
IV. ERP with variation in pricing methodology (country basket, price calculation by min., average or taking discount into account, reference price revision timing)	A. Including inappropriate countries in one basket for price referencing, could lead to either overpricing or underpricing; B. Price calculation principle based on min. or average without taking into account product volume, including price discount could again misguide price comparison like in A.; C. Regularity and timing of price revision could have effect on price level variation frequency;
V. ERP in INN or branded drug prescription market	ERP country baskets with brand prescription would propagate more inflated prices than country baskets with INN prescription.
VI. ERP in branded market with INN product replacement	ERP comparison among such markets would reach faster price convergence;
VII. ERP in market with variation in reimbursement level	ERP effect on access, availability and affordability is related to price reimbursement level, or copayment level;
VIII. ERP in market with additional pricing regulation (IRP, price linkage, mandatory discount)	ERP among countries with different local price competitive systems could put an artificial barrier to competitive action by companies in order to prevent spillover effect and thus hinder market competition price reduction effect;

However, the ERP effect on price reduction will be offset by companies' product launch sequencing strategies. They can produce a feedback effect on price through the exploitation of loop R1's reinforcing cycle, by registering the highest public price in the first country of launch and then transferring that price to the rest of the reference country markets through the ERP benchmarking rule. In this scenario, there will be no effect on product availability, due to the lack of price reduction related incentives to leave a local market.

Scenario II is related to a market with competition among patented and off patent drugs. The ERP effect on access will again be a delay in product entry due to launch sequencing strategies to exploit the upward reinforcing effect of the ERP regulation. However, due to market competition, the effect on access delay should be less than that in Scenario I. The ERP effect on price affordability will be zero if reimbursement is full. The lower the reimbursement the lower the affordability, i.e. the higher the patient copayment.

However, depending on the level of competition, the discounted drug market price can increase affordability but will have no connection to the ERP regulation, as the public drug price can remain high. However, the ERP can have an effect on drug availability, i.e. an effect on drug exit, when the ERP cross-country reference feedback could lead to a downward price convergence. This occurs if the market price discounts are made public and pricing authorities take them into consideration when applying the ERP regulation. In Scenario III, related to a market with parallel trade, the ERP effect would stay the same as in Scenario II. However, the parallel drug import/export supports the company's strategy to supply locally higher priced drugs in order to provide no incentive for the parallel traders who profit from local drug price differences. In this way, the parallel trade appears as an external factor to the ERP effect, supporting companies launch sequencing strategies and a delay in local drug access.

Scenario IV is related to national variations in the ERP application regarding the scope of the country basket, price calculation formula (i.e. by minimum, average, and or taking market price discount into account), reference price revision regularity and timing, etc. Including inappropriate countries in one basket for price referencing could lead to either an overpricing or underpricing effect of ERP, i.e. undermined access and affordability in the former, and access and availability in the latter. If the price calculation method is based on the minimum or average without taking into account product volume, and or including market price discount, this could again misguide the price comparison and lead to the above mentioned ERP effect. Regularity, i.e. doing a price revision more or less often, could have an effect on the price level variation frequency and accelerate or delay the ERP effects outlined above.

It should be noted that the RAM presented in section 9 aims to analyse the ERP effect on firms supply and pricing behaviour and not to provide an analysis of the effect of competition. However, competition is reflected in the scenario analysis as being a contextual factor that has an impact on the ERP effect on the drug market. Also, the AbM shows that firms can engage in competitive actions like price discounting ('Action: Compete on price discounting instead of price reduction'). This is also shown in the RAM by connecting the agent pricing rule 'PricingRule' with the 'CompetitivePriceDiscount' variable.

Through considering each scenario and turning point, a decision maker can explore how and in what circumstances the ERP effects in the system may change, and thus can take an informed decision to improve the system behavior in accordance to decision objectives. For example, control over the relevant turning points could lead to drug suppliers maintaining higher prices for longer or improved price containment for the government ('ERPEffect' and 'InitPubPrice' turning points and agents' 'ERPRule' and 'PricingRule'). Another outcome may be a delayed launch decision by the drug agents, leading to product unavailability for certain countries ('DecisionSupply' and agents' 'SupplyRule') due to ERP effect avoidance behaviour or market exit due to prices getting decreased beyond a minimum threshold. These insights are relevant for pricing policy makers who can use the RAM to improve their local ERP rules in connection to the local governments equitable access, affordability and availability objectives.

The above qualitative analysis demonstrates that applying a RAM approach can enable a comprehensive evaluation (taking account of both resource-feedback and agent-based perspectives) of the ERP effect on drug equitable access, affordability and availability. It can also produce a rich picture of the market dynamics, and can provide problem structuring insights, including scenario generation and identification of possible system improvement interventions. In addition, the analysis extends previous research on the ERP, helping to overcome previous limitations (Toumi et al., 2014, Vogler et al. 2015). Scenario identification can therefore support policy making to improve the ERP regulation by introducing changes aimed at offsetting the effect of the regulation on drug access delay, unaffordability and unavailability in EU local markets.

11. Discussion and future potential for RAM applications

This paper proposes an integrated RAM framework as a novel PSM to aid resource/agent complex system analysis. This has been possible through the support of resource/agent related theories such as Resource based Theory, Resource Dependence Theory, Behavioural Decision Theory and Anticipatory Systems Theory, which provide rich perspectives on the comprehensive management of complex adaptive systems.

This section will revisit the motivation for this paper, highlight its contribution and discuss the limitations of the work and future extensions.

Motivation and contribution

The development of the enhanced RM and the novel AMs and their hybridisation in a RAM were motivated in three ways:

(i) researchers identifying the needs of future PSMs, to take account of interdisciplinary perspectives, borrowing theory and developing procedures for integrating different modelling methods (Ackermann et al. 2014).

(ii) the application of agent based, and resource-feedback approaches have traditionally been carried out from the individual perspectives of resource structure or agent behaviour. These are opposing macro/micro, and resource/agent perspectives. The lack of a joint conceptual/qualitative hybrid model building procedure led to calls for hybridisation of both of these perspectives (Guerrero et al. 2016; Scholl 2001; Schieritz 2002).

(iii) a need to maintain a "comprehensive perspective" (Rosenhead 2006) of complex adaptive systems

In accordance with the key challenges of borrowing and developing theory, and developing a conceptual framework and procedure for combining different methods (Ackermann et al. 2014; Howick & Ackermann 2011), our paper's main contribution is to combine resource related theories with agent behavioural related theories, to develop a novel RAM problem structuring approach which can maintain a "comprehensive perspective" (Rosenhead 2006) to complex adaptive systems.

The paper demonstrates how a RM technique can be enhanced through adding an external resource perspective, thus taking account of external resource dependence, through the Resource Dependence Theory. The novel AMs (AiM and AbM techniques) provide a means for capturing agents ''cognitive structure" (Anderson 1999; Macal & North 2015) and fill a gap in AB modelling practice, related to a lack of a conceptual modelling approach, through bringing in Behavioural Decision Theory and Anticipatory Systems Theory. Furthermore, this can aid conceptualization and validation (Heath et al. 2009; Klügl 2008; Kasaie & Kelton 2015) through visualisation of agents' cognitive structure in the form of an "if/then" condition action map, depicting agents' actions and the conditions they depend on.

Combining AM and enhanced RM into a hybrid RAM can provide a comprehensive resource/agent perspective to complex adaptive system research by capturing agents' behaviour related to system resources, and their interrelations.. Application of the RAM framework can also provide insight into the key "turning points" in the system subjected to the effect of the agents' adaptive behaviour.

Placing the RAM framework within the different resource and agent theories can ensure its theoretical and methodological consistency. From a mixing methods perspective, the RAM approach can also provide a theoretically sound and structurally robust methodological procedure for mixing SD and AB modelling and simulation.

Limitations

The AMs and RAM are applied to a practical research question as an illustrative example of their design and purpose. However, further testing of the RAM is required through applications in other context areas where it can be used for qualitative analysis and as a procedure for the quantitative hybridisation of SD and AB approaches.

The resource/agent mapping approach proposed here represents a more complex method than applying methods that only take a resource or agent perspective. It will therefore require more time and expert capabilities to safeguard against errors. However, due to its comprehensive appreciation of a complex adaptive system, involving both resource and agents' interconnections, the hybrid mapping approach can compensate for the limitations of applying only one method, which may neglect important interconnections between system elements. In relation to the above, the more complex theoretical framework applied, although providing richer analytical apparatus, would require prior knowledge of the main theoretical principles that are guiding the RAM methodological application. This could be a barrier to the proper application of the approach, and thus may require user guidelines to be designed.

Future extensions

In addition to being a novel problem structuring method, a RAM can also be used as a hybrid qualitative conceptual modelling procedure for resource and agent interactive systems such as pharmaceuticals and health care. Conceptual modelling is acknowledged to be a key tool for model validation and confidence building in health care and aims to help the structural modelling and validation (Roberts et al. 2012) procedure. Validation and confidence building focuses on the correspondence between the real world phenomenon under examination and a simulation model (Marshall, Burgos-liz, et al. 2015) in an iterative, transparent and visualised process. (Law, 2009) This aims to ensure qualitative and quantitative (Eddy et al. 2012) consistency between the real world and a simulation. A hybrid RAM can strengthen the integration process between the resource and agent modelling approaches, and confidence building among modellers and users (Howick et al. 2008; Macal 2010), by applying it as a joint conceptual modelling procedure. This ensures that the qualitative modelling stage is theoretically and methodologically consistent with a quantitative simulation modelling phase.

As demonstrated in section 10, the RAM application can provide a means for rich scenario identification, and a procedure for hybrid scenario simulation exploration. In the ERP example, this has the capacity to inform development of an efficient and sustainable drug pricing regulatory environment. This ERP example will be extended into a hybrid SD and AB simulation model for scenario testing and experimentation, which the authors will report on in another article. This hybrid simulation model will represent a quantitative translation of the qualitative RAM, thus ensuring conceptual validation and procedural consistency of the simulation modelling process. This will include quantitative coding of both SD and AB modelling, , connecting agent rules and resource inflow and outflow rates to ensure connected performance.

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Appendix I Table I. ERP information sources

Information Source	Goal	Documentation record	Timing
ERP working group of a European medicines industry association;	To analyse and define generic industry official position in comparison to the innovative industry position	Memorandums, meeting minutes, observer notes	2015 2016 2017 2018
Participating in a board and Price Regulation task force of a national drug industry association;	To analyse and define Bulgarian Industry position	Same as the above	2015 to 2018
Meetings on the topic with authorities /decision makers;	To understand health authorities position and build consensus	Observer notes	2015 to 2018
Drug industry position letters	To reflect on official industry position	Official position papers	2015 to 2018

Table II. Key Resources identified relevant to ERP

Internal and External Resources	Description	Influencing factor
Medicinal product	Medicinal products are a key resource and are related to demand and supply side of the pharmaceutical market. Critical attention of the healthcare authorities is directed to guaranteeing drug timely access, affordability and availability	Manufacturing agent Level of demand Level of supply Product price
Product official price	Product price is a resource connected to economic rent for the manufacturers and suppliers, and to economic expenditure for the healthcare funds and consumers. Critical attention of the healthcare authorities is directed to contain drug expenditure by reducing product max allowed price	Pricing regulation Government Manufacturing agent
Product market price	A competitive price formed after a discount is given off the official price to the payer and distribution agent	Government Manufacturing agent Competition
Doctors	Key for drug prescribing volume and drug allocation Pharmaceutical companies compete for control over that resource	Manufacturing agent Prescribing regulation, i.e. by brand or by INN
Patients	Key for generating product demand	Doctor agent Product information
Public drugs budget	Key resource supporting product demand and supply Critical attention is directed to its distribution among drug categories through different level of reimbursement	Healthcare fund Reimbursement regulation Product demand and product supply
Drug price information	Important for price elasticity level and product switching	Government Agents along the supply chain

Table III. Key Agents identified relevant to the ERP

Agents	**Description**	**Influencing factor**
Innovative companies	Main market agents producing original drugs protected by patent and data exclusivity	Price regulation; Competition Level of demand Parallel Export Import
Generic drug companies	Main market agents manufacturing the same drug molecules after patent expiration	Price regulation Competition Level of demand
Government	Main agent setting the pricing regulation on a local market	Limited drug budget Level of demand and supply Companies lobbying
Doctors	Main prescribing agent	Companies detailing Other incentives
Pharmacy units	Main dispensing agent	Financial incentives like discounts
Patient	Main consuming agent	Prescribing doctors Information Pharmacists