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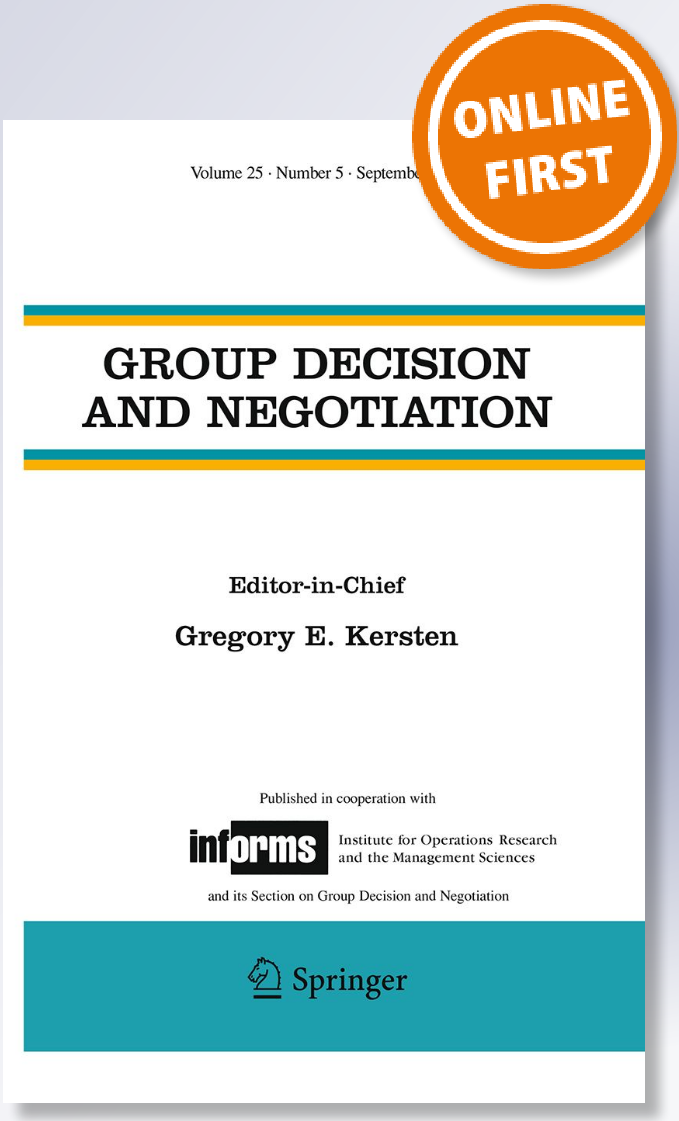
Group Decision and Negotiation
Published in cooperation with the Institute for Operations Research and the Management Sciences and its Section on Group Decision and Negotiation

ISSN 0926-2644

Group Decis Negot
DOI 10.1007/s10726-019-09643-4



Springer

Group Decision and Negotiation
https://doi.org/10.1007/s10726-019-09643-4

Evaluating the Stability of the Oil and Gas Exploration and Production Regulatory Framework in Brazil

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Abstract

This paper proposes to use game theory and equilibrium solution concept approaches to model and evaluate the stability of the oil and gas E&P regulatory framework in Brazil. We initially modeled the oil and gas E&P market as a non-cooperative multicriteria game and then applied the solution concepts presented in the GMCR methodology for evaluating the stability of the modeled game. There are indications that the logic behind the modeled game of choosing an adequate regulatory regime for the Brazilian oil and gas E&P market is similar to the classical game of Battle of the Sexes. Following the logic of this game, it is suggested that only in the presence of strong guarantees that the eventual sacrifice of players' payoffs in the short or medium term will be compensated in the future, the regulatory framework of the oil and gas E&P market in Brazil can be considered stable.

Keywords Game theory · Battle of the Sexes · Stability · Oil and gas

1 Introduction

In the last decades, three changes were responsible for major modifications in the Brazilian oil and gas exploration and production (E&P) market. The first two changes were part of privatization and regulatory reforms implemented in several sectors during the 1990s (Prado 2012), including the monopoly breaking of the Brazilian state-owned company (Petrobras) in 1997, and the adoption of the concession regime through public and open auctions. In this context, an independent regulatory agency was created, the *Agência Nacional do Petróleo* (ANP) (Brazilian Petroleum

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Published online: 08 November 2019

Agency), which is responsible for the regulation of the oil and gas E&P market in the country. The main objective for the creation of ANP was to protect the interests of Brazilian society and to bring predictability to its E&P market (Florêncio 2016). The third major change was the adoption of a production sharing contract (PSC) regime for the areas considered strategic by the Brazilian government. Currently, the Brazilian regulatory framework is characterized as a hybrid system, where the concession and PSC regimes are adopted in different regions due to their particular characteristics (Tolmasquin and Pinto Junior 2011). Nonetheless, Almada and Parente (2013) argued that a robust regulatory framework is still a current challenge for the Brazilian E&P market.

The design of an adequate regulatory framework is a complex problem due to the distinct interests of governments and companies involved in the E&P market. In the process of harmonizing these different interests, conflicts might occur (Saaty and Ergu 2015). Matbouli et al. (2014) defined that conflict is a complex decision-making situation, where two or more agents (individuals or organizations) pursue different and eventually discordant goals. This complex situation can be summarized as a set of agents, criteria and alternatives, in which a payoff can represent the relative satisfaction of an agent over each alternative by their criteria performance evaluation in relation to agent's preferences. For modeling this kind of situation, commonly faced in societal systems, game theory can be applied for providing solutions based on equilibrium solution concepts (Hipel and Fang 2005).

Various types of games have already been categorized according to certain characteristics of their strategic interactions. These games usually have a simplified form, aiming to capture the essence of strategic interaction in order to be applied in real conflictive situations. Robinson and Goforth (2005) proposed to organize games with two players and two alternatives in a unified framework based on the logic of their payoff structure, which includes among them the following five most common topologies: (1) Prisoner's Dilemma, modeled with strong incentives to choose non-coordinated strategies; (2) Stag Hunt, modeled with some of the coordinated strategies with higher outcomes; (3) Chicken Game, modeled with coordinated strategies as the least-favored outcomes; (4) Battle of the Sexes, modeled with the coordinated strategies with different and mirrored outcomes; and (5) Coordination Game, modeled with strong incentives to choose coordinated strategies. All these games are classified as non-cooperative games, since they are modeled without the provision of a phase where players can communicate for trying to guarantee their agreements (Binmore 2007). Araujo and Leoneti (2018) provide examples of such games applied for modeling oil and gas industry decision-making problems.

The solution of non-cooperative games is based on equilibrium solution concepts. Fang et al. (1989) depicted and grouped different equilibrium solution concepts in the Graph Model for Conflict Resolution (GMCR) methodology. According to Hipel et al. (2011), the jointly evaluation of equilibrium solution concepts can take into account uncertainty and psychological aspects with regards to conflict analysis, by tracking the potential moves and counter-moves of individuals involved in a group decision-making situation. The GMCR methodology suggests the adoption of Nash Equilibrium concept and also the following five equilibrium solution concepts: (1) General Metarationality (GMR) (Howard 1971); (2) Symmetric Metarationality

(SMR) (Howard 1971); (3) Sequential Stability (SEQ) (Fraser and Hipel 1979); (4) Limited-Move Stability (L_h) (Zagare 1984; Fang et al. 1993); and (5) Non-Myopic Stability (N-M), a particular case of Limited-Move Stability (L_h) (Brams and Wittman 1981).

The application of game theory in order to model and solve group decision-making process of E&P market is not new, as can be seen in Virine and Murphy (2007), Lopes and Almeida (2013), Willigers et al. (2009), Willigers and Hausken (2013), Esmaeili et al. (2015), Castillo and Dorao (2012), Schitka (2014), Amorelli and Carpio (2016), Yang et al. (2013), Wood et al. (2016), and Araujo and Leoneti (2018). Nevertheless, there is a scientific gap in the study of the stability of the solutions involved in the search for an adequate regulatory framework of the Brazilian E&P market. For this reason, it is proposed here to model the oil and gas E&P market in Brazil as a non-cooperative multicriteria game,[1] and to apply different equilibrium "solution concepts" for evaluating the stability of the solution found to the game. A utility function for modeling group multicriteria problems as games (Leoneti 2016) is used to accomplish the game modeling phase, while the equilibrium solution concepts of the GMCR methodology are applied to solve the game.

The paper is organized as follows: (1) Sect. 2 details the main aspects regarding the modeling stage, from the proposition of the multicriteria game until the calculation of the players' payoffs; (2) Sect. 3 presents the procedure to solve the multicriteria game by applying six different equilibrium solution concepts (Nash, GMR, SMR, SEQ, Limited-Move, Non-Myopic); (3) Sect. 4 shows the assessment of the equilibria found, focusing on their stability in short, medium and long term scenarios, and in the main logic behind the modeled multicriteria game; and (4) Sect. 5 presents the final considerations and remarks.

2 Modeling the Multicriteria Game and Calculating the Payoffs

This paper proposes to use game theory and equilibrium solution concept approaches to model and evaluate the stability of the oil and gas E&P regulatory framework in Brazil. We initially modeled the oil and gas E&P market as a multicriteria game by using a utility function for modeling group multicriteria decision making problems as games, as proposed by Leoneti (2016). We then applied the equilibrium solution concepts of the GMCR methodology, as proposed by Fang et al. (1989), including: (1) Nash equilibrium (Nash 1951); (2) General Metarationality (GMR) (Howard 1971); (3) Symmetric Metarationality (SMR) (Howard 1971); (4) Sequential Stability (SEQ) (Fraser and Hipel 1979); (5) Limited-Move Stability (L_h) (Zagare 1984; Fang et al. 1993); and (6) Non-Myopic Stability (N-M) (Brams and Wittman 1981). The main goal was to evaluate the stability of the solutions found in the modeled multicriteria game. Finally, the regulatory framework of the Brazilian E&P market were assessed in the light of the multicriteria game modeled and the solutions found.

[1] Multicriteria games are also known in the literature as vector games.

Firstly, it has been assumed that the designer of the multicriteria game in the name of Brazilian society is the regulatory agency ANP. Florêncio (2016) states that ANP can be seen as an autonomous and independent regulator agent with the main goal of protecting the interests of Brazilian society in the E&P market from governmental and private entities' interferences. This division of the E&P market is shared in the view of Johnston (2008) who proposed the division of the E&P market into two main players: (1) the local government, characterized as the resource owner; and (2) the exploration companies, defined as the owners of the financial and operational resources to be applied in the oil and gas E&P activities. Other authors corroborates this division, such as Johnston (1994), Nakhle (2008, 2015), Manaf et al. (2016), Tordo et al. (2010), and Willigers et al. (2009).

The second stage was the players' objectives definition regarding their particular interests. Towards that, it is essential to understand the choice dilemma faced by the designer of the game, which needs to balance government participation and E&P projects' profitability (Tolmasquin and Pinto Junior 2011). The typical objectives identified in the literature for the local governments are: (1) government take maximization (Johnston 1994; Tolmasquin and Pinto Junior 2011; Nakhle 2008); (2) establishment of mechanisms to control E&P activities, such as minimum exploration programs, and local content policies (Bain Company and Tozzini Freire Advogados 2009; Tolmasquin and Pinto Junior 2011; Tordo et al. 2013); and (3) the country's overall socioeconomic and technological development (Tolmasquin and Pinto Junior 2011; Nakhle 2008). On the other hand, the exploration companies have different objectives in an E&P market, such as: (4) optimization of their profit margins (Johnston 1994, 2008; Nakhle 2008); (5) stable political, juridical and economic frameworks (Johnston 1994; Nakhle 2008); (6) concise, simple-to-understand and low administrative costs systems (Nakhle 2008, 2015); (7) managerial and operational control of E&P activities (Johnston 1994; Bain Company and Tozzini Freire Advogados 2009); and (8) balanced division of the incomes generated (Nakhle 2008, 2015; Tordo et al. 2010).

A literature review was also performed for studies that present evaluating criteria related to the different objectives found for the players in the oil and gas E&P market. It is possible to highlight the study performed by Manaf et al. (2016), which developed a framework to quantify the most important aspects for the evaluation of an E&P market that were grouped into four criteria: (1) equity, affordable measurement of profit margins and associated risks; (2) certainty, business environment stability and perspectives of arbitrary changes; (3) convenience, fiscal system structuring and efficiency of regime administration; and (4) economy, simplicity and transparency of regulatory frameworks. In addition to the four criteria identified by Manaf et al. (2016), two other criteria were included: (5) government take, used to assess the degree of participation of the state in the incomes generated by the oil and gas industry (Consoli 2015; Tolmasquin and Pinto Junior 2011; Bain Company and Tozzini Freire Advogados 2009; Alberta 2009); and (6) level of government control, characterized by the operational and managerial activities control, production level control, and local content policies (Tolmasquin and Pinto Junior 2011; Bain Company and Tozzini Freire Advogados 2009; Tordo et al. 2013).

Table 1 Preliminaries

Players	Criteria	Alternatives
Local governments (P1)	Government take (C1)	Concession (A1)
	Control level (C2)	Production sharing Contract (A2)
	Equity (C3)	
Exploration companies (P2)	Certainty (C4)	Service contract (A3)
	Convenience (C5)	
	Economy (C6)	Joint-venture (A4)

Also through a literature review, the following regulatory framework systems were identified as potential alternatives to the multicriteria game: (1) concession, combining a robust legal-regulatory stability, creating strong incentives for private investments (Nakhle 2008), and a lower level of government control of the E&P activities (Bain Company and Tozzini Freire Advogados 2009), being widely used by developed countries such as Canada and Norway; (2) PSC, maintaining the resources' ownership in the hands of the state, as well as greater participation in the operational and managerial activities, resulting in a low level of autonomy for the companies (Johnston 1994), being used by countries such as China, Indonesia and Nigeria; (3) service contract, applied by countries where exploration of resources is an exclusivity of the state or its national oil company (NOC), in which private companies have little or no access to the E&P market (Johnston 1994, 2008; Tolmasquin and Pinto Junior 2011), such as Saudi Arabia and Iran; and (4) Joint-Venture, characterized as a partnership or association between the exploration companies and the state, usually through their state-owned companies, i.e. Venezuela (Bain Company and Tozzini Freire Advogados 2009). In summary, in concessional systems, exploration companies have resource ownership after production, while in contractual systems (PSC, service contract and joint-venture), resource ownership remains with the state (Johnston 1994, 2008; Nakhle 2008, 2015; Tordo et al. 2010). Table 1 summarizes the first part of the modeling process.

Regulatory framework studies available in the literature were used to measure the criteria performance for assembling the decision matrix. Government Take (C1) was valued based on the average of direct quantitative measurement of the studies of Bain Company and Tozzini Freire Advogados (2009) and Alberta (2009). Equity (C3), and Certainty (C4) criteria were valued based on the average of direct quantitative measurement as proposed in Araujo and Leoneti (2019). Finally, Control Level (C2), Convenience (C5), and Economy (C6) criteria were valued based on the average of a qualitative assessment performed by the present authors using as reference the studies of Tolmasquin and Pinto Junior (2011), Bain Company and Tozzini Freire Advogados (2009), Nakhle (2008, 2015), and Tordo et al. (2010). The range of all evaluation criteria was defined as an extended Likert scale, where the value of 9 was assigned to the highest ranked country (benchmarking), and the value of 1 was assigned to the lowest ranked country. Table 2 presents the decision matrix of the present problem, which

Table 2 Decision matrix

	Government take (C1)	Control level (C2)	Equity (C3)	Certainty (C4)	Conveni-ence (C5)	Economy (C6)
Concession (A1)	4.5	3.6	6.5	7.8	5.9	6.4
Production sharing (A2)	5.8	6.4	5.5	6.4	4.9	3.7
Service contract (A3)	8.2	8.2	2.9	5.3	2.3	2.6
Joint-venture (A4)	8.8	9.0	1.0	1.0	1.5	1.0

Table 3 Preference rank order for each player and their respective WVs

	Local governments (P1)	Exploration companies (P2)
1st	Government take (0.408)	Equity (0.408)
2nd	Control level (0.242)	Certainty (0.242)
3rd	Equity (0.158)	Convenience (0.158)
4th	Economy (0.103)	Economy (0.103)
5th	Convenience (0.061)	Government take (0.061)
6th	Certainty (0.028)	Control level (0.028)

contain the average performance of each alternative through criteria and that was validated by the evaluation of an oil and gas E&P market expert.

For eliciting the preferences of players and obtaining a relative weighting vector (WV) of each player involved, it was chosen the Rank-Ordered Centroid (ROC) method, since ordinal information can be used when the little information about agents' preference is known (Barron and Barret 1996). The ROC method proposed by Barron and Barret (1996) can be summarized in Eq. (1)

$$\omega_i(k) = \frac{1}{c}\sum_{j=k}^{c}\frac{1}{j}, \quad k = 1, 2, \ldots, c \tag{1}$$

where the value of $\omega_i(k)$ represents the component of the WV related to k order of the ranking designated to the criteria of the ith player, and c corresponds to the number of criteria. The following two boundary conditions need to be satisfied: $\omega(1) \geq \omega(2) \geq \cdots \geq \omega(c)$ and $\omega(1) + \omega(2) + \cdots + \omega(c) = 1$. In this particular case of six criteria, the WV values were the following: $\omega(1) = 0.408$; $\omega(2) = 0.242$; $\omega(3) = 0.158$; $\omega(4) = 0.103$; $\omega(1) = 0.408$; $\omega(6) = 0.028$. Therefore, the most important criterion of each player will be multiplied by $\omega(1)$, and so on up to the sixth criterion. Then, according to a literature review of the likely interests of local governments and exploration companies over the evaluating criteria, their preference rank order were arbitrarily defined by the present authors and validated by an oil and gas E&P market expert, and were transformed into WVs for each player using Eq. (1), as described in Table 3.

Table 4 Payoff tables

Local governments (P1)					Exploration companies (P2)				
	A1	A2	A3	A4		A1	A2	A3	A4
A1	0.306	0.310	0.229	0.167	A1	0.984	0.682	0.223	0.02
A2	0.342	0.475	0.413	0.336	A2	0.687	0.685	0.224	0.02
A3	0.327	0.453	0.648	0.577	A3	0.239	0.238	0.227	0.02
A4	0.298	0.412	0.591	0.595	A4	0.028	0.028	0.027	0.021

Following, the multicriteria game was defined as the quadruple $<N, M, C, \gtrsim_i>$, where N is the set of n players, M is the set of m actions, C is the set of c criteria, and $\gtrsim_i$ is the preference set over M for each player $i \in N$. The numeric representation of the strategic interaction among each player $i \in N$ and their preferences over the alternatives M is given by the algebraic operator $\gtrsim_i$, which is proposed by the use of the utility function π_i: $\mathcal{R}^n_+ \rightarrow [0, 1]$, as presented in Leoneti (2016), according to Eq. (2)

$$\pi_i(x, y) = \varphi(x, IA) \cdot \varphi(x, y) \cdot \varphi(y, IA) \tag{2}$$

where the variable x is the player's initial alternative, y indicates the alternative that other player proposes, IA is the ideal alternative, representing the utopist alternative of player i having all criteria settled as the maximum, the value of n represents the number of players, and $\pi_i(x, y)$ defines for each player i, the payoff for the strategic interaction process when the counterpart offer a alternative from the set of M alternatives. The main component of the utility function is a pairwise comparison function $\varphi_{(x,y)}$, calculated in Eq. (3),

$$\varphi_{(x,y)} = \left[\frac{\alpha_{xy}}{\|y\|}\right]^{\delta} \cdot \cos\theta_{xy}, \quad where \quad \delta = \begin{cases} 1, & if \quad \alpha_{xy} \leq \|y\| \\ -1, & otherwise \end{cases} \tag{3}$$

where $\alpha_{xy} = \| x \| \cdot \cos\theta_{xy}$ and $\| y \| = \sqrt{y_1^2 + y_1^2 + \cdots + y_c^2}$. The players' likely strategies consider the fact that they might trade for alternatives that have higher outcomes given by the pairwise comparison function between the alternatives and the ideal solution. In other words, it is derived from the fact that they want to increase, or at least keep their outcome in a trade.

Finally, the decision matrix of Table 2 is standardized using the vector standardization procedure and each of the WV presented in Table 3 is applied to this standardized decision matrix, which generates two weighted and standardized decision matrixes, one for each respective player. The utility function shown in Eq. (2) is then applied to each one of the standardized decision matrices, which generates the payoff tables of each player, representing the players' satisfaction for each possible strategy in the modeled game. Table 4 presents the payoffs table of each player of the multicriteria game, where the player chooses row and the counterpart chooses column (the transposition of one matrix is necessary, but not

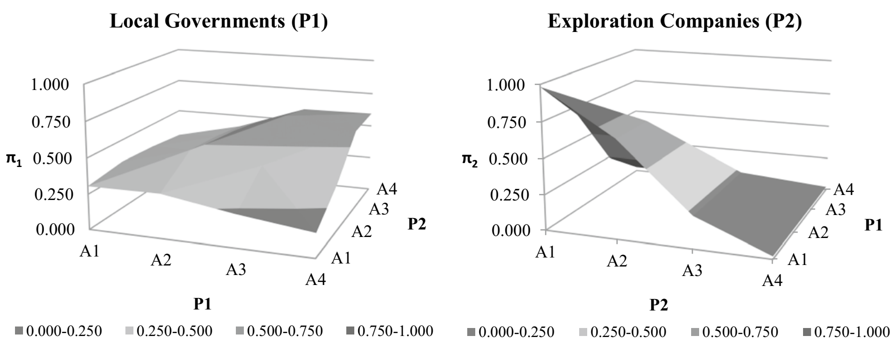

Fig. 1 Decision space

presented at this point). Figure 1 shows the payoffs in the decision space based on the players' strategic interaction.

In summary, the Brazilian oil and gas E&P market was modeled by the creation of the decision matrix (Table 2), and its subsequent standardization and weighting by using the elicited WVs that were calculated based on the rankings of Table 3 and Eq. (1), generating one weighted and standardized decision matrix for each player. Equation (3) was then applied to each of these matrices to create the respective square matrix of order M (alternatives versus alternatives), which contains the comparison between the alternatives for each player, including the pairwise comparison of the alternatives to the IA. Finally, Eq. (2) was used to aggregate all the calculated components, resulting in the outcomes shown in Fig. 1.

In a preliminary analysis, it can be noticed that local governments (P1) demonstrated more preferences on alternatives of service contract (A3) and joint-venture (A4). Diversely, exploration companies (P2) had preferences significantly concentrated on alternative of concession (A1), when compared to the payoffs obtained by the other options (A2, A3 and A4). In this sense, it can be visualized that both players have very distinct and antagonistic interests in this modeled game. It can be observed that alternative A1 is highly preferable for player P2 ($\pi_2(A1, A1) = 0.984$) due to a payoff value that is very close to unity, which is the maximum possible payoff. However, as part of a group decision making situation, the players need to find a jointly solution, in this case an adequate regulatory framework solution for the E&P market that could reasonably satisfy the agents involved in this multicriteria game. Consequently, it is proposed to solve the game through the application of equilibrium solution concepts.

3 Solving the Modeled Game Through Different Equilibrium Solution Concepts

The GMCR methodology introduced by Fang et al. (1989) recommend the adoption of the Nash Equilibrium concept and the following five other equilibrium concepts: (1) General Metarationality (GMR), which considers a counter-attack action in

Table 5 Modeled game

		Exploration companies (P2)			
		A1	A2	A3	A4
Local governments (P1)	A1	0.306; 0.984	0.310; 0.687	0.229; 0.239	0.167; 0.028
	A2	0.342; 0.682	0.475; 0.685	0.413; 0.238	0.336; 0.028
	A3	0.327; 0.223	0.453; 0.224	0.648; 0.227	0.577; 0.027
	A4	0.298; 0.020	0.412; 0.020	0.591; 0.020	0.595; 0.021

Table 6 Possible solution states of the modeled game

		Exploration companies (P2)			
		A1	A2	A3	A4
Local governments (P1)	A1	State 1	State 5	State 9	State 13
	A2	State 2	State 6	State 10	State 14
	A3	State 3	State 7	State 11	State 15
	A4	State 4	State 8	State 12	State 16

response to the unilateral action of other player that aim to improve its payoff (Howard 1971); (2) Symmetric Metarationality (SMR), similar to GMR, but with the possibility of three movements, being able to capture the players' counter-reactions (Howard 1971); (3) Sequential Stability (SEQ), similar to GMR, but with restricted possible responses to the action of other player that aim to improve its payoff (Fraser and Hipel 1979); (4) Limited-Move Stability (L_h), greater freedom in the analysis of moves and counter-moves through a sequential game of "h" moves (Zagare 1984; Fang et al. 1993); and (5) Non-Myopic Stability (N-M), a particular case of Limited-Move Stability (L_h), where the game ends as soon as the original state is reached, and players cannot make any further moves (Brams and Wittman 1981). The main particularity of Limited-Move and Non-Myopic Stability techniques is that the game is analyzed as a sequence of movements and counter-movements expressed as an extensive game that allows the evaluation of the possible players' threats and promises, and whether these movements can be taken into account or not (Madani and Hipel 2011). Several application cases of the GMCR methodology and equilibrium solution concepts can be visualized in Kilgour and Hipel (2005), Hipel et al. (2011), Madani and Hipel (2011), Madani (2013), Hipel et al. (2014), Esmaeili et al. (2015) and Kinsara et al. (2015).

For the application of the equilibrium solution concepts, it is proposed by the GMCR method the aggregation of the payoff matrix of each player into a new matrix form, where the first value indicates the specific payoff of player P1 and the second value represents the transposed payoffs of player P2, as demonstrated in Table 5. Also, according to the procedures of GMCR methodology, this aggregation is the requisite for the formation of possible solution states, where each state represents a possible scenario for the multicriteria game. The possible solution states are summarized in Table 6, where

Table 7 Stability analysis of the modeled game

	Solution State															
	1		2		3		4		5		6		7		8	
	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
Nash		■	■								■	■				
GMR		■	■	■		■				■	■	■	■	■	■	
SMR		■	■	■		■				■	■	■	■	■	■	
SEQ		■	■							■	■	■				
L_2		■								■		■				
L_3		■								■		■				
N-M		■								■		■				

	Solution State															
	9		10		11		12		13		14		15		16	
	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
Nash					■	■									■	■
GMR		■	■	■	■	■	■			■	■	■	■	■	■	■
SMR		■	■	■	■	■	■			■	■	■	■	■	■	■
SEQ		■			■	■						■			■	■
L_2					■											
L_3					■											
N-M					■											

sixteen possible solution states can be observed. The application of the equilibrium solution concepts was performed based on the players' respective rationality.

Madani and Hipel (2011) divided the six equilibrium solution concepts considered in the GMCR according to three main characteristics, namely: (1) forecast horizon; (2) willingness to disimprove; and (3) knowledge of players' preferences. The forecast horizon is characterized as the number of movements or degrees of reflection allowed to players before finally choosing their decision, where the first movement has no consideration of other players reactions (e.g. Nash equilibrium), the second movement considers the player's reactions (e.g. GMR and SEQ), the third movement takes into account a possible counterattack (e.g. SMR), and the possibility of variable movements with greater freedom in the number of moves allowed (e.g. Limited-Move and Non-Myopic). The willingness to disimprove represents the players' possibility of choosing unilateral moves with lower payoffs, including never allowing these unilateral moves (e.g. Nash and SEQ), the possibility of reduction of opponents' satisfaction (e.g. GMR and SMR), and the strategic reactions and counter-reactions by temporarily allowing a less preferable alternative choice in order to achieve a better outcome (e.g. Limited-Move and Non-Myopic). Finally, knowledge of players' preferences is defined as the knowledge of preferences, where players are only aware of their own preferences when making their decisions (e.g. Nash, GMR and SMR), or have the possibility of taking into account the preferences of all the players involved (e.g. SEQ, Limited-Move and Non-Myopic).

The usage of different equilibrium solution concepts aimed to search for balanced and stable solutions for the game presented, in order to reflect as best as possible the real world characteristics of the players' behaviors, which usually have different levels of foresight, willingness to make strategic moves, and distinct risk attitudes (Madani and Hipel 2011). In other words, the main goal is to find the outcomes or solution states that are stable under various stability definitions. The outcomes found for Nash, GMR, SMR, SEQ, Limited-Move (L_2, L_3, L_4, and L_h for $h > 4$) and Non-Myopic (N-M) solution concepts can be visualized in Table 7.

Table 8 The classical game of Battle of the Sexes

	Wife (W)	
	Football (F)	Ballet (B)
Husband (H)		
Football (F)	2, 1	− 1, − 1
Ballet (B)	− 1, − 1	1, 2

Table 9 Stability analysis of the classical game of Battle of the Sexes

	Solution State							
	State 1 (F/F)		State 2 (B/F)		State 3 (F/B)		State 4 (B/B)	
	H	W	H	W	H	W	H	W
Nash Eq.	■	■					■	■
GMR	■	■					■	■
SMR	■	■					■	■
SEQ	■	■					■	■
L_2	■							■
L_3	■							■
N-M	■							■

4 Evaluating the Stability of the Proposed Solutions to the Modeled Game

By considering Limited-Move (L_h) and Non-Myopic (N-M) equilibrium solution concepts, player 1 presents stable solutions only for state 11 (alternatives A3/A3). In other words, player 1 would present high stability when choosing alternative A3 jointly with player 2. Conversely, by assessing the same techniques, player 2 strongly demonstrates stability around the alternatives A1 and A2, which can be seen for state 1 (A1/A1), state 5 (A1/A2), and state 6 (A2/A2). In this sense, it is possible to assume that player 2 has a strong inclination for the solution states that include the alternatives A1 and A2. Both Limited-Move (L_h) and Non-Myopic (N-M) solution concepts take into account the possible threats, promises, and blocks that every player involved in the game can apply, where it is possible to evaluate their sequence of moves and counter-moves with a very long foresight (Madani and Hipel 2011). It is noteworthy however, that there is no match for these two equilibrium solution concepts in the game modeled. Consequently, this game has only solutions when the number of moves and counter-moves is not high, such as the case of Nash, GMR, SMR and SEQ. In this sense, it can be noticed that there is a lack of stable solutions in scenarios with long forecast horizon and high willingness to disimprove, as observed by the outcomes of Limited-Move (Lh) and Non-Myopic (N-M) stability concepts.

The logic presented in the modeled game can be compared to the classical game of Battle of the Sexes. Luce and Raiffa (1957) detailed this game as the evaluation of two entertainment options for a couple, where the husband (H) would rather attend to a football match event and the wife (W) prefers going to a “ballet audition”, but they want to go together (Table 8). Considering that both players have their respective maximum payoffs only when other players choose their preferable alternative, and that they mutually know their preferences, the game only has stable solutions when there is not many moves and counter-moves by players or high willingness to disimprove. In this sense, a possible criterion to break this asymmetry is the players' sacrifice of their payoffs in the belief that they will be compensated in the future, derived by their gains provided when others players sacrifice their payoffs as well. The six stability definition concepts of this classical game can be seen in Table 9.

It can be seen that Nash, GMR, SMR and SEQ solution concepts had the same results indicating the solutions of state 1 and state 4 as possible stable solutions. Both solution states represent scenarios with minimal moves and counter-moves, where players coordinate their actions and agree to go to the same event, even with initial conflicting interests. On the other hand, Limited-Move (L_h) and Non-Myopic (N-M) suggest that no solution state is stable for both players. The main conclusion is that no alternative is stable for both players under all the stability concept techniques, especially when long foresight techniques are considered, which seems to correspond to the logic of the modeled game of choosing an adequate regulatory framework for the Brazilian oil and gas E&P market. In this sense, the dynamic of the conflict of interest presented in the Brazilian oil and gas E&P market makes the search for stable solutions a challenging task, because it is unlikely that players' interests would be adequately accomplished by a unique alternative, regardless of the alternative chosen.

5 Conclusions

By the analysis of this practical case, it was possible to find indications that the logic behind the modeled game of choosing an adequate regulatory regime for the Brazilian oil and gas E&P market is similar to the classical game of Battle of the Sexes. The reasoning behind this game suggests that in this real world situation, either local governments have their interests accomplished by their favorite alternative, which is service contract, or the exploration companies have their goals achieved by selecting either the concession or production share alternatives. Hence, regardless of the alternative chosen, at least one of the players will have a considerably higher satisfaction associated with a different option. Consequently, it is suggested that the possible solutions are stable within a foreseeable future, without too many moves and counter-moves involved or willingness to disimprove. This fact might be an indication that only in the presence of strong guarantees that the eventual sacrifice of payoffs in the short or medium term will be compensated in the future, the regulatory framework for the oil and gas E&P market in Brazil can be considered stable.

The main contribution of this work to the literature is to provide fresh outlooks about how difficult it is to a regulator agency to equate the distinct interests of the players involved in choosing a regulatory regime for the oil and gas E&P market, namely local governments and exploration companies. Due to the usage of a game theory approach enriched by equilibrium solution concepts, it was possible to find that some solutions could be fairly acceptable, however no alternative can be considered stable for all the players involved. In other words, one player will always have more satisfaction associated with a distinct alternative. The methodology proposed for modeling a multicriteria group problem as a multicriteria game and solving it by the application of the GMCR methodology, in order to understand and quantify the players' preferences and to find balanced and stable solutions, is another contribution to the literature. This framework could also be potentially applied in other similar real world situations.

Acknowledgements To CAPES for the scholarship in the program DS-CAPES and for the commentaries of the anonymous reviewers that were very important for the improvement of the paper.

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