Strategic Execution of a Smart City Project: A Game Theoretic Model between Government Agencies and Citizens

by

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Abstract

Smart cities are the newly digitized cities that utilize technology like the Internet of Things (IoT) and Information Communication Technology (ICT). Most of the projects involved are being planned and implemented by the government. There are crucial decision-making steps that need to involve the opinions of the citizens in order to maximize the output of each project. In order to achieve this, game theory can be used to model the interactions between the government and citizens. A sequential game model with a mixed strategy is used in this thesis. The results are obtained by performing a one way sensitivity analysis. The parameters that are considered are varied with respect to the expected utility of the government and the citizens. By performing this analysis, the best strategies of the government and the citizens can be identified. My results show the visualizations of the decisions being made by both the players that can help to optimize the output strategies.

Chapter 1

Introduction

The 21st century is an era in which artificial intelligence and smart technology is at its peak. Data is the 21st century's gold and how we use it is important. Almost every field today uses data, some of them being, education, transportation, urban planning, healthcare, manufacturing, media & entertainment, Internet of things, government, and a lot more. An important application of data is in building sustainably balanced smart cities.

Smart cities have played and will play a more important role in various aspects of human life, like health, energy and education. The main *attributes* of a smart city are: sustainability, quality of life, urbanization and smartness. Domains like infrastructure, governance, social issues, climate change, and pollution fall under 'sustainability'. Aspects like transformation from rural to urban, technology, and economy come under 'urbanization'. Improving and uplifting social, economic and environmental benchmarks can be considered to be in the 'smartness' bracket. 'Quality of life' (QoL) is the well-being of citizens, both emotionally and financially. Another important factor of a smart city is ICT (Information Communication Technology). As such, there is no universal definition of ICT, but it can be referred to as network components, their applications and systems that aid people and big industries to interact in the digital world. It connects the human world to the digital world. [1]

Today, there are smart cities being built all over the world. Some of them are successfully built, whereas others are not. Some of the top smart cities in the world, according to CIMI (Cities in Motion Index) as of 2018 are New York, London, Paris, Tokyo, Reykjavik, Singapore Seoul, Toronto, and the list goes on. [2] It is based on the ranking of factors like its governance, urban planning, technology, environment, international outreach, social cohesion, mobility & transportation, human capital, and economy. With India under its new governance, Prime Minister Narendra Modi, there are serious attempts to build successful smart cities in order to help the citizens of India and India as a whole to grow. In order to carry out this dream, the Government of India have established programs like the SMART City Mission and AMRUT (Atal Mission for Rejuvenation and Urban Transformation) to carry out the necessary projects. The focus of this thesis is limited to the development of SMART cities in India.

Impact of the projects in India:

Number of proposals	100
Total Urban Population impacted	100 million across the country
Total Cost of Projects	$28 Billion (includes area-based development and Pan-city solutions)

Table 1.1: 'Smart Cities Mission' impact in India

The results achieved by the government on execution of projects by the 'Smart Cities Mission' in India are promising for the future. In the period of January 2016-January 2018 the costs of the projects tendered are worth $4.8 billion. In the period of January 2018-February 2019 the costs of the projects tendered are worth $18.5 billion. Smart Cities

Mission (SCM) has a plan to smarten up 100 cities in India. To prove that Smart Cities Mission and Prime Minister Narendra Modi's vision of India's bright future can work, SCM has taken a subset of the 100 cities (a batch of 20 cities), and created proposals and started executing projects to improve those cities. The table 1.2, shows good results of the SCM in one year (2018-2019), and hence proves that his smart cities vision has hope to work on the entire nation.

Dholera, a town in the regional state of Gujarat, is chosen by its former Chief Minister, Narendra Modi, to be converted to India's first smart city. The city is master planned by a UK-based global consultancy firm, Halcrow, and partially funded by the Indian state, as well as Japanese corporations. The area of Dholera is 920 square kilometers, some of which is developable and the rest, ideal for renewable projects. It has now entered a phase of entrepreneurial urbanization, which plans on enhancing the urbanization for economic growth. The expected completion year of the project is 2040. It will create jobs for about 800,000 people and a roof over 2,000,000 people. [9] This is the government's perspective and outlook given to the citizens. On the contrary, some of the citizens living in the area are not very comfortable with these ideas. Modi shepherded in a Special Investment Region (SIR) act in March 2009, which gives more power to the state to acquire land for the purpose of building the smart city. But many locals see it as a way to bypass the land acquisition act.[7] Many more contradictions like this have risen between the government and the citizens which lead to formation of JAAG (Jameen Adhikar Andolan Gujarat) activists, farmers and opposition leaders. These kinds of situations lead to protests, disputes and violence between the two players involved. To avoid this chaos and to facilitate better urban planning, citizen participation is highly encouraged. A game theoretic approach can be adopted to study the strategic interactions between these major players involved: the public agencies, private firms, and the citizens, to help make better decisions which can help achieve the expectations of all the players. The concept of a sequential game with a mixed strategy is used to form the model between the two players: the government and the citizens. Backward induction is a powerful concept that can be applied only to perfect information games, and it is used to solve the game model in this project. [4][5] After solving the game model, sensitivity analysis is done by setting default values to the parameters to obtain the best strategies from the model. The tools used for the analysis are Python 3 and Microsoft Excel.

The rest of the thesis is organized as follows. Chapter 2 will consist of the literature review on some similar game models, a background on smart cities, and the importance of citizen participation. Chapter 3 talks about the intricacies of the model, from the basic structure to the solutions. The results and analysis of the model are discussed in detail in Chapter 4 of the Thesis. Chapter 5 and 6 conclude the thesis with the references.

Chapter 2

Literature Review

2.1 Game Models used in the cases of urban planning

Today, urbanization is the goal of almost every government. Existing urban cities want to be more urbanly developed than they already are, and rural towns want to advance to the level of a basic urban city. The government plays the most important role in planning a city for its citizens. As mentioned earlier, citizen participation is very important, as the citizens are the ones reaping the benefits of the urban lifestyle. Zhang et.al; 2016 considers the peasants' opinions to safeguard their rights and interests in terms of keeping or giving up their land due to the change in urban development. A behavioral game is modelled in this paper between the government and the peasants to address the issue. Hui et.al; 2013 uses a sequential game between the government and farmers to involve the latter in the decision making process. Their paper addresses the gap that involves land conflicts and interests between the farmers and the government due to urbanization. Batty; 1977 uses a stochastic game model to evaluate conflicts related to urban planning and design. There are four sections to this paper. The first one highlights the bargaining and power positions of the players involved, the second has some conceptual game theory models that shines light on a case study based on the choice of location of a town to accept overspill population from a large conurbation, and the third & fourth sections have the algorithms & applications of the model, respectively. A land-use spatial optimization using game theory and genetic optimization is used to coordinate competitions of land-use patterns. Game theory plays an important role in understanding the land conflicts between the government and the farmers. A repeated game is played between the government and farmers to negotiate the dominance of the land. (Liu et.al; 2015)

2.2 Smart Cities: The future of Urban Civilization

As mentioned earlier, the amount data is accelerating at an abundance with respect to time. And with a lot of data, the world is getting digitized at the same alarming rate. Due to these changes, the "luxury" of urbanization is slowly becoming a "necessity". Smart cities are a broader part of digital cities and are assigned to the software and service layer of the digital cities architecture. There are different layers in this architecture like the Data Layer, User Layer, Infrastructure Layer, etc., which describes different attributes (like Web/Virtual Cities, Knowledge based cities, broadband cities, etc.,) needed to support the smart city context. On the other hand, urban planning has its own dimensions. They are environmental protection, sustainable residential development, resources capitalization, and coherent regional growth support. Both urban planning and smart cities go hand-in-hand with each other. Various e-service portfolios can be offered in a modern smart city that will benefit the public, environment and authority residing within the city. Some examples are, *e-government services* which take care of issues like public complaints, job searches, etc., on both a local and national level, *e-learning services* that offer enhanced and distant education and learning material, *e-healthcare services* which can focus on offering distant support to citizens who are unable to move, *intelligent transportation* that improves the quality of life, and simultaneously offering advanced tools like traffic monitoring, measurement and optimization. The interrelation could be measured with the meeting points of their dimensions and layers. (Anthopoulos et.al; 2012)

2.3 The importance of Citizen Participation

There is some work done linking citizen satisfaction and trust with the government. Mukumbareza; 2015 had done extensive research to evaluate citizen satisfaction with the quality of e-government services in South Africa and found different satisfaction & trust levels in different parts of South Africa. Whereas in Yemen, the satisfaction and trust levels were lower than expected (Salim; 2017). In developing countries like India, Africa, Yemen, etc., the citizen satisfaction levels are very variable and not as high as those of developed countries like U.S.A, or some countries in Europe. Citizen participation is a crucial part of increasing these levels of satisfaction. If the citizens participate in decision making of projects, the government can improve their services that will benefit both the parties with respect to time, energy, decision-making, alignment of goals and satisfaction. Citizen objectives and techniques have been identified by Glass; 1979 which can aid and improve citizen participation. There is no specific technique that satisfies all the objectives, but instead it depends on the situation at hand.

2.4 The Literature gap at hand

In this day and age, most of the projects proposed or conducted are in some way contributing to the development of a smart city. India is falling behind on smart technology when compared to the leading cities in the world, and that is why India was chosen as a target, to improve decision-making on project implementation. There have been game models related to land conflicts in China (as mentioned in section 2.1), but this project goes beyond land conflicts. The problems and solutions are more directed towards preserving the quality of life of citizens, and eradicating poverty. Additionally, international companies are not setting up base in India as we are not as digitally advanced asother smart cities. The most crucial projects which have a high impact on the society should involve active citizen participation. For example, the emerging and upcoming Dholera city project in India is the development of the first smart city in the country. The voice of the citizens in this case are not being heard, and there should be ways and means to involve citizens in the decision-making process. This can ensure better development of the city and all future smart city projects. In order to consider the voice and opinions of the citizens, game theory can be used to create a model between two players: the government and the citizens.

Chapter 3

The Model

3.1 Notations

The government and citizens have decisions to make at each step. All the possible options they have are as follows:

(a) Options of the government

1. 'U_{EWC}' represents the first move that the government could make, i.e., to execute a project without consulting the citizens.

2. '$U_{P, EE}$' represents an alternative to 'U_{EWC}', i.e., to propose a project and executes the project regardless of the citizens' liking the proposal or not.

3. '$U_{P, E, NE}$' represents the government's move to propose a project and to either execute it if the citizens' like the proposal or not execute it if the citizens' do not like the proposal.

4. 'U_N' is the government's option to do nothing.

All of the options are better understood in Chapter 3 of the thesis.

(b) Options of Citizens

A = When the government executes the project without consulting the citizens and the execution is good, *the citizens support the proposal.*

B = When the government executes the project without consulting the citizens and the execution is bad, *the citizens protest.*

C = When the government executes the project without consulting the citizens and the execution is bad, *the citizens do not protest.*

D = When the government proposes a project to the citizens and the citizens like it, the government executes the project, and *the citizens protest.*

E = When the government proposes a project to the citizens and the citizens like it, the government executes the project, and *the citizens do not protest.*

F = When the government proposes a project to the citizens and the citizens do not like it, the government executes the project, and *the citizens protest.*

G = When the government proposes a project to the citizens and the citizens do not like it, the government executes the project, and *the citizens do not protest.*

H = When the government proposes a project to the citizens and the citizens do not like it, the government does not execute the project, and *the citizens seek improvement of the proposal*.

I = When the government proposes a project to the citizens and the citizens do not like it, the government does not execute the project, and *the citizens do nothing.*

J = When the government does nothing, *the citizens seek technological improvements to initiate project ideas.*

K = When the government does nothing, *the citizens do nothing.*

Parameters	Description
P	Political Rewards earned by the government
P_2	$P*a$, where $a \in [0,1]$ such that $P_2 \leq P$
P_1	P_2*b , where $b \in [0,1]$ such that $P_1 \leq P_2 \leq P$
C_e	Cost of project execution
w	Urban development factor & smartness level of project
k	Project execution index, where $k \in (0,1]$
w_1	$w_1 = kw$, where $w_1 \leq w$
C_p	Cost of citizens protesting
C_i	Cost of citizens seeking/demanding improvements
q	Probability of the project execution being good
p	Probability of citizens liking the project proposal
S_c	Satisfaction level of citizens
e	Loss/Disruption avoided due to protesting/seeking improvement
e_1	e_1*m , where $m \in [0,1]$ such that $e_1 \leq e$

Table 3.1: List of parameters with their description

Table 3.1 contains the notations of the parameters and a short description explaining its significance.

(c) Decision Variables

Decision Variables	**Description**
$x_i, \quad \forall\, i \in \{1,2,3\}$	Government's decision (i^{th} branch) at the 1st stage
$x_{ij}, \quad when\; i = 2\,, j \in \{1,2,3\}$	Government's decision (j^{th} branch) after the citizens' chance node of liking or disliking the government's proposal
$y_{ik}, \quad when\; i = 1, k \in \{1,2,3\}$ $when\; i = 2, k \in \{1, \dots, 6\}$ $when\; i = 3, k \in \{1,2\}$	Citizens' decisions (k^{th} branch) after the government makes its decision (i^{th} branch)

Table 3.2: List of Decision Variables

Table 3.2 contains the notations of the decision variables with its significance. The game tree model (Figure 3.1) visually places these parameters and decision variables at each node and branch.

3.2 The Game Tree

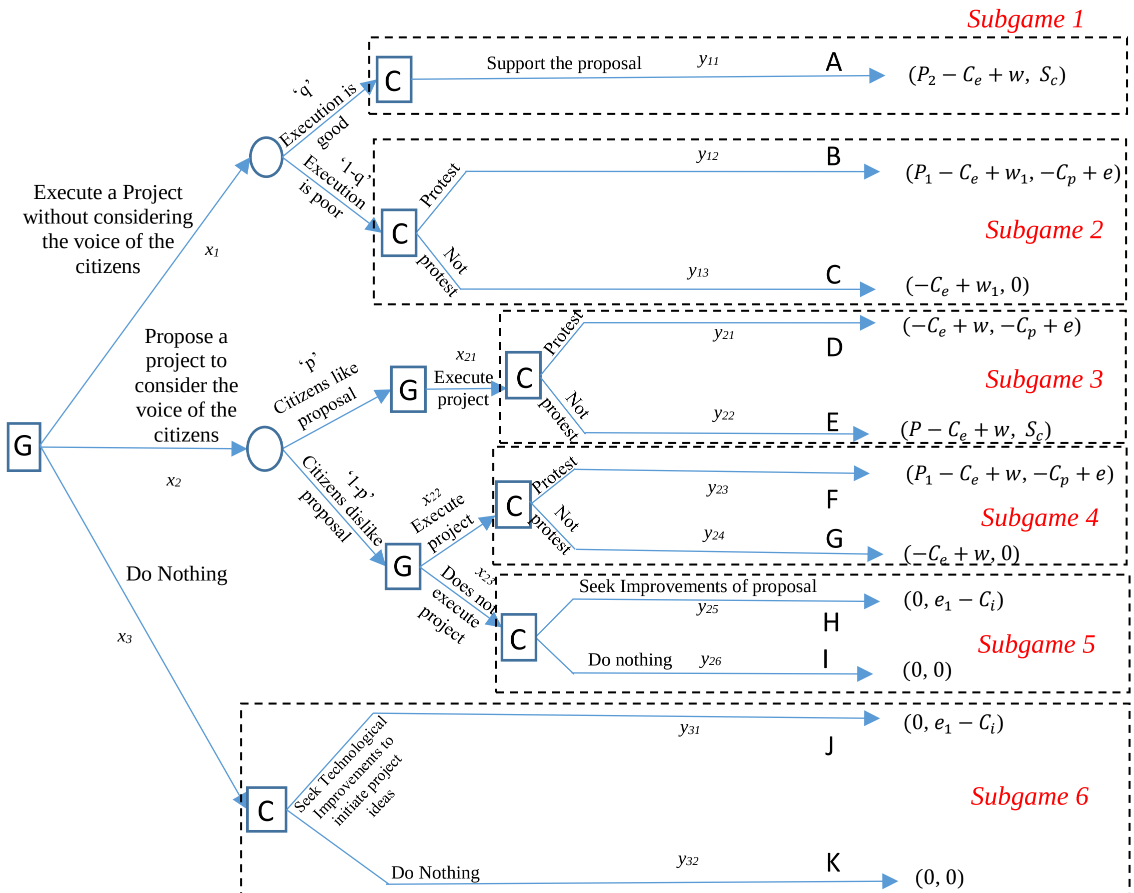

Figure 3.1: Game Model

Figure 3.1 represents the sequential game tree model between the government and the citizens. The government makes the first move in the decision-making process, as the authority of decision-making lies in the hands of the government. The three options that the government have to make are to either execute a smart city project without considering the opinions of the citizens, or to propose a project to the citizens to consider their opinions, or do nothing.

If the government decides to choose the *first option* i.e., to execute a smart city project without considering the opinions of the citizens, there will be an uncertainty node which signifies whether the execution will be good (with a probability 'q') or not (with a probability ‘$1-q$’). Not every project can have a good execution. Some projects can have a bad execution because of some uncontrollable failures, miscommunication between the project manager and his/her coworkers [6], or some unforeseen circumstances, which is the reason why there is an uncertainty node signifying the execution of the project. If the execution turns out to be good, the citizens would support the model, as they have no reason to do anything otherwise. At the end of this node, the payoffs that the government will receive is political rewards (P_2, where $P_2 \leq P$), and the urbanization and smartness level of the respective project (w). The political rewards are rewards earned/obtained by the government or any political party from a project being executed. For example, a minister getting his electoral votes from the citizen can be taken as rewards. [7] The reason why another variable, P_2 instead of P, which is less in magnitude can be considered is because, in this case (the second branch of the government at the first stage), the government executes the project without considering the voice of the citizens. The urbanization and smartness level factor involves smartness development of the city with respect to the urbanization. The project can be based on many urban factors like environment, technology, population, economic growth, etc., which go hand in hand with the smartness factors like governance, urban planning, international outreach, social cohesion, mobility, transportation, economy, and human capital. [8] There is a cost of execution which comes out of pocket from the government (C_e) every time a project is being executed. The citizens will have one payoff at the end of the first node (A), which is their Satisfaction level (S_c). This payoff shows how satisfied the citizens are with anything related to the project. If the execution is poor, the citizens have the option to protest or not. If the citizens decide to protest (B), the government’s payoff will consist of the same payoffs, namely, political rewards (P_1, such that $P_1 \leq P_2 \leq P$), cost of execution of the project and the urbanization and smartness level of the respective project (w_1, such that $w_1 \leq w$). There is a small difference between the two. The first one as observed is that the political rewards obtained are even less than the political rewards at the end of the first node. There are two reasons for this. The first reason is that the execution of the project is done without considering the citizens' opinions, and the second is that the execution turned out to be poor. The other difference between the payoffs in the first and the second nodes is the urbanization and smartness level of the project (w_1), which is smaller than w. This is due to the execution being poor. The citizens will have a negative cost, i.e., the cost of protesting (C_p), and a positive payoff 'e', which is the loss/disruption avoided due to protesting. The loss that could occur due to a poor execution could put citizens' lives at stake, for instance, the citizens could lose land, jobs, or even their own homes. If the citizens decide not to protest (C), the government would not get political rewards at all, as there is no reason for the citizens to give it. There will be the cost of execution and, the urbanization and smartness level of the respective project (w_1). The citizens do not have any payoffs at the end of this node as there is nothing positive or negative that the citizens are going through.

Moving on, the government has the power to choose the *second option,* i.e., to propose a smart city project to the citizens, to actually consider their opinion. When this decision is taken, there is a probability ('p') of the citizens liking the proposal, and of course, they do not like the proposal with a probability '$1 - p$'.

Let us consider the group of nodes, when the citizens like the proposal. The government would execute the project if the citizens like it, because they have absolutely no reason to not execute the project (since the government proposed it). The citizens would have the options to protest or not. If they decide to protest (D), the government would only have to pay for the project execution and the payoff would be the urbanization and smartness level of the respective project (w). They political rewards are none, because the citizens decided to protest. This node never occurs and hence it is a dominant node. If the citizens decide not to protest (E), the government would definitely get political rewards (P), and the other payoffs would be the cost of execution and the urbanization and smartness level of the respective project (w). As observed, the political rewards is greater in this node than any other, because this is the ideal positive situation between the government and citizens. A positive satisfaction level of citizens would be considered as the citizens' payoff (S_c).

Moving on to the group of nodes when the citizens dislike the proposal, the government has two options, either to execute the project or not. If the government decides to execute the project, the citizens, again, could decide to protest or not. At the end of the node where the citizens decide to protest (F), the government has political rewards (P_1), cost of execution, and the urbanization and smartness level of the respective project (w), as their payoffs. 'P_1' is considered here because the government executes the project even though the citizens dislike the proposal. This is a dominating node. The citizens' payoffs at the end of this node is the same as their payoffs at the end of the fourth node. If the citizens decide not to protest (G), the government's payoffs will be the same as their payoffs in the fourth node. There are no political rewards because the government executed the project even though the citizens disliked the proposal, and they are unable to protest. The citizens' payoffs will be zero, as the citizens will not be satisfied with the outcome. On the contrary, if the government does not execute the project, the citizens would have the option to seek improvement of the proposal or not do anything. If they decide to seek improvements of the proposal (H), the government would not have any payoffs. This is because there is no project execution taking place and the government would not have earned anything. On the other hand, the citizens will get a payoff. They have a cost to seek improvement (C_i), and a loss avoided due to seeking improvement (e_1). Over here the loss avoided will be less, as the damage done is less. The possible loss that could be caused due to seeking improvement will be fairly less than the loss caused due to protesting. If the citizens decide to do nothing (I), there will be no payoffs.

Apart from the two options, the government has a third one as well. The government could decide to not do anything. In this case, the citizens, in some way or the other, could seek technological improvements to initiate unique project ideas in order to contribute towards the development of smart cities (J). If they decide to seek improvements, the government would not get any payoffs, as they did not do anything at all. The citizens' payoffs would be the same as their payoffs in the tenth node. The other option the citizens have is to also do nothing. If this option occurs, there would not be any payoffs for both the players.

3.3 Model Solutions

3.3.1 Objectives of the two players

The maximum utilities of both the players are given below.

$$\boldsymbol{U_C}(\boldsymbol{x},\boldsymbol{y}) = x_1\{qy_{11}S_c + (1-q)\left[y_{12}\left(-C_p + e\right)\right]\}$$
$$+ x_2\{px_{21}\left[\, y_{21}\left(-C_p + e\right) + y_{22}\, S_c\right]$$
$$+ (1-p)\left[x_{22}y_{23}\left(-C_p + e\right) + x_{23}y_{25}(e_1 - C_i)\right]\} + x_3\{y_{31}(e_1 - C_i)\}$$

$$\boldsymbol{U_G}(\boldsymbol{x},\boldsymbol{y}) = x_1\{qy_{11}(P_2 - C_e + w) + (1-q)[y_{12}(P_1 - C_e + w_1) + y_{13}(-C_e + w_1)]\}$$
$$+ x_2\{px_{21}\,[\,y_{21}(-C_e + w) + y_{22}\,(P - C_e + w)]$$
$$+ (1-p)[x_{22}[y_{23}(P_1 - C_e + w) + y_{24}(-C_e + w)]\}$$

The maximum utility of the citizens' is $\boldsymbol{U_C}(\boldsymbol{x},\boldsymbol{y})$ and that of the government is $\boldsymbol{U_G}(\boldsymbol{x},\boldsymbol{y})$. The objectives of the citizens include maximization of their payoffs (loss avoided due to protesting/seeking improvements, and satisfaction level), and the minimization of their costs (cost of protesting/seeking improvements). Similarly, the government wants to maximize their payoffs (political rewards, urban development and smartness level factor) and minimize their costs (cost of project execution) as well.

3.3.2 Response functions of the citizens

(a) Subgame 1

In this subgame, the citizens have only one option, to support the project.

Best Response function:

$$\hat{y}(x) = A$$

(b) Subgame 2

In this subgame, the citizens have to decide between options B and C.

Best Response function:

$$\hat{y}(x) = \begin{cases} B, & if \;\; e > C_p \\ C, & if \;\; e \leq C_p \end{cases}$$

(c) Subgame 3

In this subgame, the citizens have to decide between options D and E.

Best Response function:

$$\hat{y}(x) = \begin{cases} D, & if \;\; e > C_p + S_c \\ E, & if \;\; e \leq C_p + S_c \end{cases}$$

(d) Subgame 4

In this subgame, the citizens have to decide between options F and G.

Best Response function:

$$\hat{y}(x) = \begin{cases} F, & if \;\; e > C_p \\ G, & if \;\; e \leq C_p \end{cases}$$

(e) Subgame 5

In this subgame, the citizens have to decide between options H and I.

Best Response function:

$$\hat{y}(x) = \begin{cases} H, & if \;\; e_1 > C_i \\ I, & if \;\; e_1 \leq C_i \end{cases}$$

(f) Subgame 6

In this subgame, the citizens have to decide between options J and K.

Best Response function:

$$\hat{y}(x) = \begin{cases} J, & if \;\; e_1 > C_i \\ K, & if \;\; e_1 \leq C_i \end{cases}$$

3.3.3 Analytical Solutions

The SPNE solutions of the model along with the expected optimal utility of the government (U_G^*) and those of the citizens (U_C^*) are provided in the table below. The optimal conditions are C_i, $\forall\ i\ \in \{1, .., 7\}$, which are illustrated below the table. The case numbers are used to illustrate the following solutions in the sensitivity analysis graphs.

Case No.	Conditions	(x^*, y^*)	U_G^*	U_C^*
1	C_1	(1, (A, B))	$q(P_2 - C_e + w) + (1-q)(P_1 - C_e + w_1)$	$q(S_c) + (1-q)(-C_p + e)$
2	C_2	(1, (A, C))	$q(P_2 - C_e + w) + (1-q)(-C_e + w_1)$	$q(S_c)$
3	C_3	(2, (E, F))	$p(P - C_e + w) + (1-p)(P_1 - C_e + w)$	$p(S_c) + (1-p)(-C_p + e)$
4	C_4	(3, (E, H))	$p(P - C_e + w)$	$p(S_c) + (1-p)(e_1 - C_i)$
5	C_5	(3, (E, I))	$p(P - C_e + w)$	$p(S_c)$
6	C_6	(4, J)	0	$(e_1 - C_i)$
7	C_7	(4, K)	0	0

Table 3.3: List of optimal conditions

Optimal conditions:

(a) For $(x^*, y^*) \equiv (1, (A, B))$. The following conditions must hold:

Condition C_1:

(i) $0 \leq q < 1$,

(ii) $0 \leq p < 1$,

(iii) $q \geq max\{\ g_1(w - w_1 - pP_1), g_1\big(w - w_1 + p(P - P_1)\big), g_1(w - w_1 - P_1), g_1(w - w_1 - P_1 + pP), g_1(p(-C_e + w) - P_1 + C_e - w_1), g_1(p(P - C_e + w) - P_1 + C_e - w_1), g_1(-P_1 + C_e - w_1)\ \}$

where $g_1 = \frac{1}{(w - w_1 - P_1 + P_2)}$

(b) For $(x^*, y^*) \equiv (1, (A, C))$. The following conditions must hold:

Condition C_2:

(i) $0 \leq q \leq 1$,

(ii) $0 \leq p < 1$,

(iii) $q > max\{\ g_2(w - w_1 + P_1 - pP_1), g_2\big(w - w_1 + p(P - P_1)\big), g_2(w - w_1), g_2(w - w_1 + pP), g_2(p(-C_e + w) + C_e - w_1), g_2(p(P - C_e + w) + C_e - w_1), g_2(C_e - w_1)\ \}$

where $g_2 = \frac{1}{(w - w_1 + P_2)}$

(c) For $(x^*, y^*) \equiv (2, (E, F))$. The following conditions must hold:

Condition C_3:

(i) $0 \leq q < 1$,

(ii) $0 \leq p < 1$,

(iii) $q < max\left\{ g_1\big(w - w_1 + p(P - P_1)\big), \frac{(w - w_1 + p(P - P_1) + P_1)}{P_2 + w + w_1}\right\}$,

where $g_1 = \frac{1}{(w - w_1 - P_1 + P_2)}$

(iv) $p > max\left\{\frac{-P_1}{P - P_1}, \frac{C_e - P_1 - w}{P - P_1 + C_e + w}, \frac{C_e - P_1 - w}{P - P_1}\right\}$

(v) $pP \geq 0$

(vi) $P_1(p - 1) < 0$

(vii) $p < 1,\ only\ if\ \{(C_e - w - P_1) \leq 0\}$

(d) For $(x^*, y^*) \equiv (3, (E, H)) = (3, (E, I))$. The following conditions must hold:

Condition $C_4 = C_5$:

(i) $0 \leq q < 1$,

(ii) $0 \leq p < 1$,

(iii) $q < max\left\{ g_1\big(-P_1 + C_e - w_1 + p(P - C_e + w)\big), \frac{(C_e - w_1 + p(P - C_e + w))}{P_2 + w - w_1}\right\}$,

where $g_1 = \frac{1}{(w - w_1 - P_1 + P_2)}$

(iv) $p > max\left\{\frac{-P_1}{P - P_1}, \frac{C_e - P_1 - w}{P - P_1 + C_e + w}, \frac{C_e - P_1 - w}{P - P_1}\right\}$

(v) $p < 1,\ only\ if\ \{(C_e - w - P_1) > 0, and\ (C_e < w)\}$

(vi) $pP \geq 0$, if $(C_e < w)$

(vii) $p \geq 0, if\ (P + w \geq C_e)$

(e) For (x^*, y^*) ≡ (4, (J)) = (4, (K)). The following conditions must hold:

Condition $C_6 = C_7$:

(i) $0 \leq q < 1$,

(ii) $0 \leq p < 1$,

(iii) $q < max\left\{ g_1(-P_1 + C_e - w_1), \frac{(C_e - w_1)}{P_2 + w - w_1}\right\}$,

where $g_1 = \frac{1}{(w - w_1 - P_1 + P_2)}$

(iv) $p > \left\{\frac{P_1 - C_e + w}{P_1}\right\}$

(v) $p < max\left\{\frac{C_e - P_1 - w}{P - P_1}, \frac{C_e - w}{P}\right\}$

(vi) $w < C_e$

(vii) $P + w < C_e$

Chapter 4

Results

4.1 Baseline Values

Parameters	Baseline Values
P	7
P_2, a	5.6, 0.8
P_1, b	1.68, 0.3
C_e	7
w	6
k	0.6
w_1	3.6
C_p	4
C_i	2
q	0.7
p	0.6
S_c	8
e	6
e_1, m	3.6, 0.6

Table 4.1: Baseline values of the parameters

NOTE: 1. All values are assumed in the above table.

2. For uniformity, each value is varied between 0 and 10 (50 values are taken).

3. In all the graphs below, the areas are defined by **(Government: move/option, Citizen: move/option)**, for example **(G: 1, C: J)** means the government is using its 1^{st} option (U_{EWC}) and the citizen is using its J^{th} option.

The reasons for the assumptions of the specific value assignments to each of the parameters in Table 4.1 are explained. A value as high as 7 is assigned to the political rewards (P) because the government values political rewards given to them by the citizens to advance in their political career, for example, electoral votes gained by ministers can be represented as political rewards. The cost of a project execution (C_e) will be a significantly large value as it is the cost of an entire project. A project, in my case, is generally funded by the government. The purpose of implementing a smart city project will be lost if the urban and smartness level factor (w) is low, hence its value is 6. The cost of citizens protesting is relatively low when compared to the cost of execution, therefore I have kept a low value of 4 for (C_p). When the cost of protesting and cost of seeking improvements are compared, the latter will be lower i.e., $C_i = 2$. This is because, generally, there are more protests that are evident when compared to citizens seeking improvements of existing problems or initiating new ideas. The probabilities q and p are randomly selected as they are considered to signify uncertainties. The satisfaction level of the citizens, S_c is given a high value 8, as the citizens' biggest and most valuable payoff is their satisfaction. The loss avoided due to protesting/seeking improvements is given a value of 6 because it is considered as a positive incentive for the citizens to protest.

4.2 Sensitivity Analysis

In this section, the sensitivity of the equilibrium solutions of the model to the changes in the parameters are studies, based on a set of baseline values. The baseline values are represented by the dashed lines in the graphs below. The solid lines represent the case transitions.

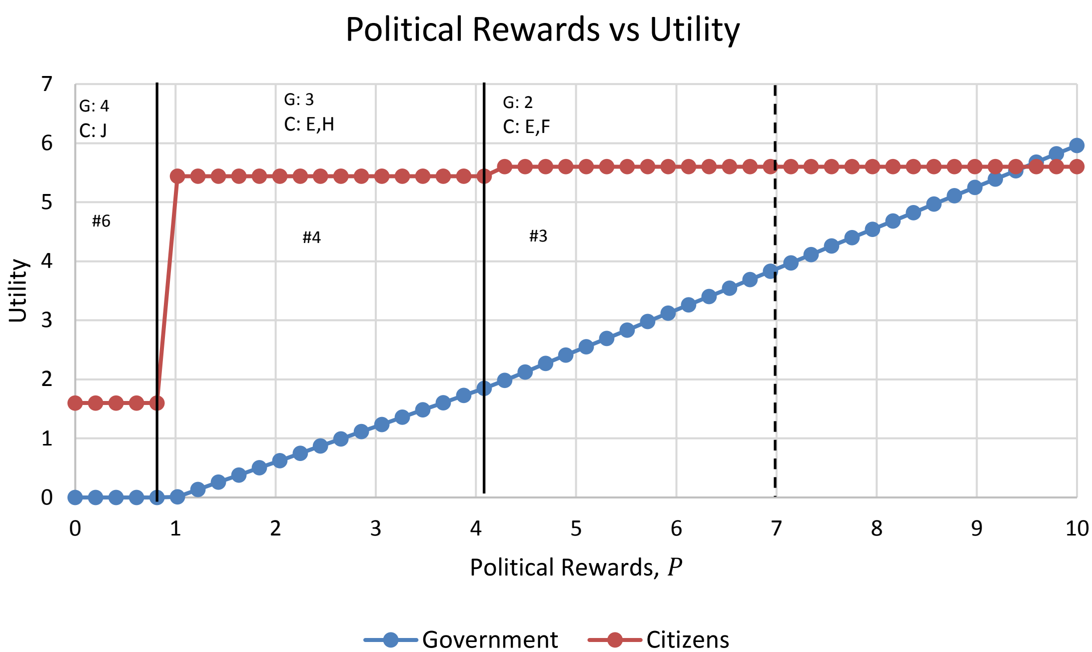

Figure 4.1: One-way Sensitivity Analysis with respect to Political Rewards

From Figure 4.1, it is observed that when the political rewards are very low ($P \leq 0.82$), the government does not do anything and the citizens decide to seek technological improvements to initiate project ideas. But as the rewards increase ($0.82 < P \leq 4.08$), the government decides to execute the project (in case the citizens like the proposal), or not execute it (in case the citizens dislike the proposal). In case the project is executed, the citizens will not protest, and in case the project is not executed, the citizens decide to seek improvements of the proposal. As the political rewards further increase ($4.08<P\leq10$), the government changes its option to execute the project regardless of the citizens' liking the proposal. So, if the citizens like the proposal, they do not protest, and if they dislike the proposal, they protest.

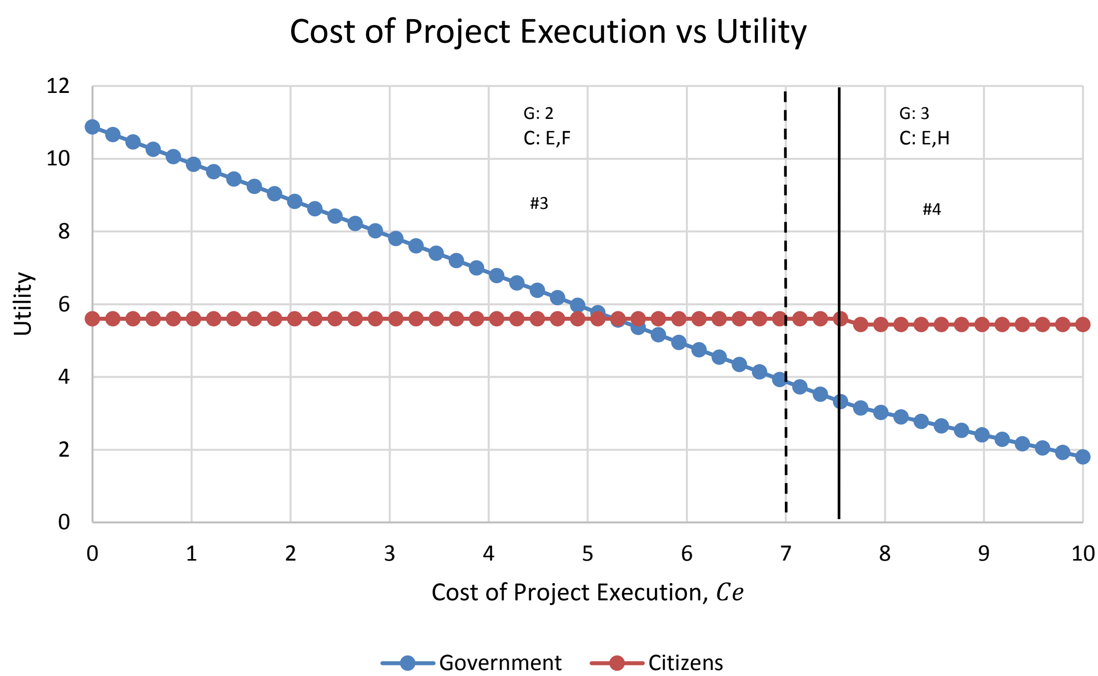

Figure 4.2: One-way Sensitivity Analysis with respect to Cost of project execution

From Figure 4.2, it is observed that with a low cost of execution ($C_e\leq7.55$), the government will execute the project regardless of the citizens' liking the proposal or not. If the citizens like the proposal, they do not protest, and if they dislike the proposal, they protest. But, with increase in the cost of execution ($C_e>7.55$), the government changes its move to executing the project (in case the citizens like the proposal), or not executing it (in case the citizens dislike the proposal). In case the project is executed, the citizens will not protest, and in case the project is not executed, the citizens decide to seek improvements of the proposal.

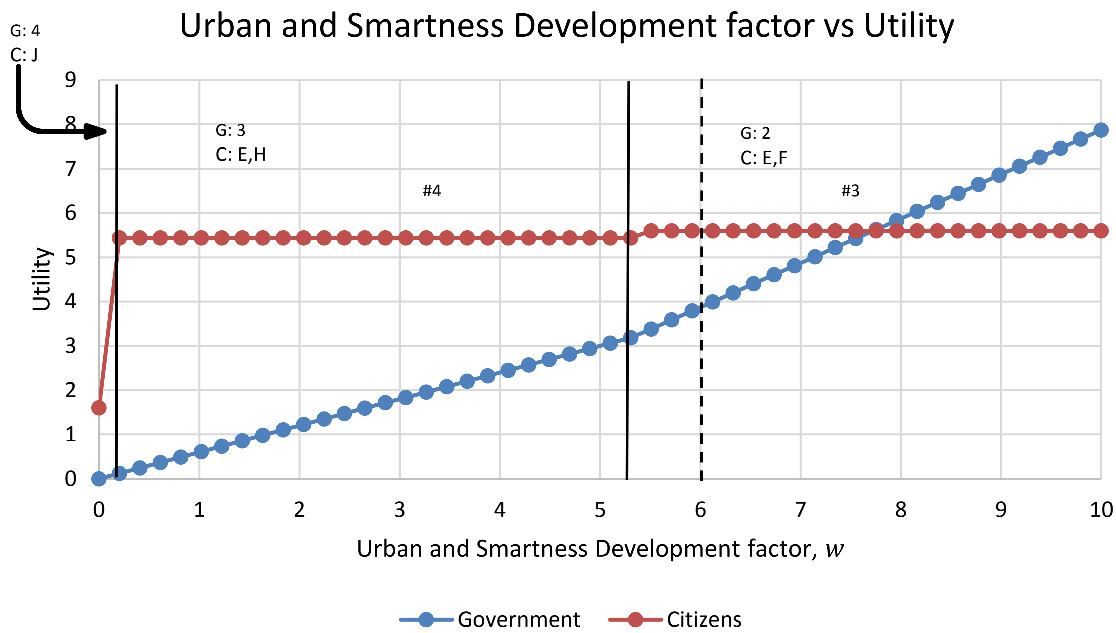

Figure 4.3: One-way Sensitivity Analysis with respect to Urban and Smartness development factor

From Figure 4.3, it can be seen that when the Urban and Smartness development factor is extremely low ($w \leq 0.204$), the government does not do anything and the citizens seek technological improvements to initiate project ideas. But as the development factor increases ($0.204 < w \leq 5.306$), i.e., the project becomes smarter and more urbanely developed, the government decides to execute the project (in case the citizens like the proposal), or not execute it (in case the citizens dislike the proposal). In case the project is executed, the citizens will not protest, and in case the project is not executed, the citizens decide to seek improvements of the proposal. When the project is highly smart and urbanized ($5.306 < w \leq 10$), the government executes the project regardless of the citizens' liking the proposal. So, if the citizens like the proposal, they do not protest, and if they dislike the proposal, they protest.

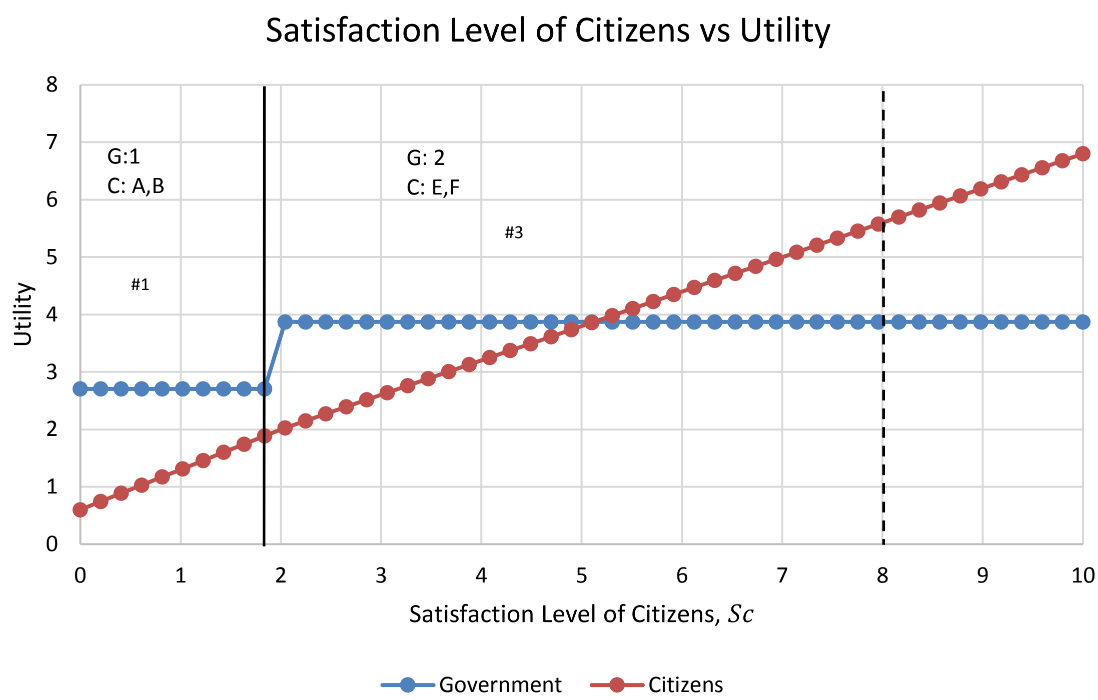

Figure 4.4: One-way Sensitivity Analysis with respect to Satisfaction Level of Citizens

From Figure 4.4, it can be observed that with a low level of satisfaction of the citizens (1.83≤S_c), the government does not really consider the voice of the citizens, but just executes the project. If the execution of the project is good, the citizens support the project, but if it is bad, they protest. But as the satisfaction level increases (1.83<S_c≤10), the government executes the project whether the citizens like the proposal or not. So, if the citizens like the proposal, they do not protest, and if they dislike the proposal, they protest.

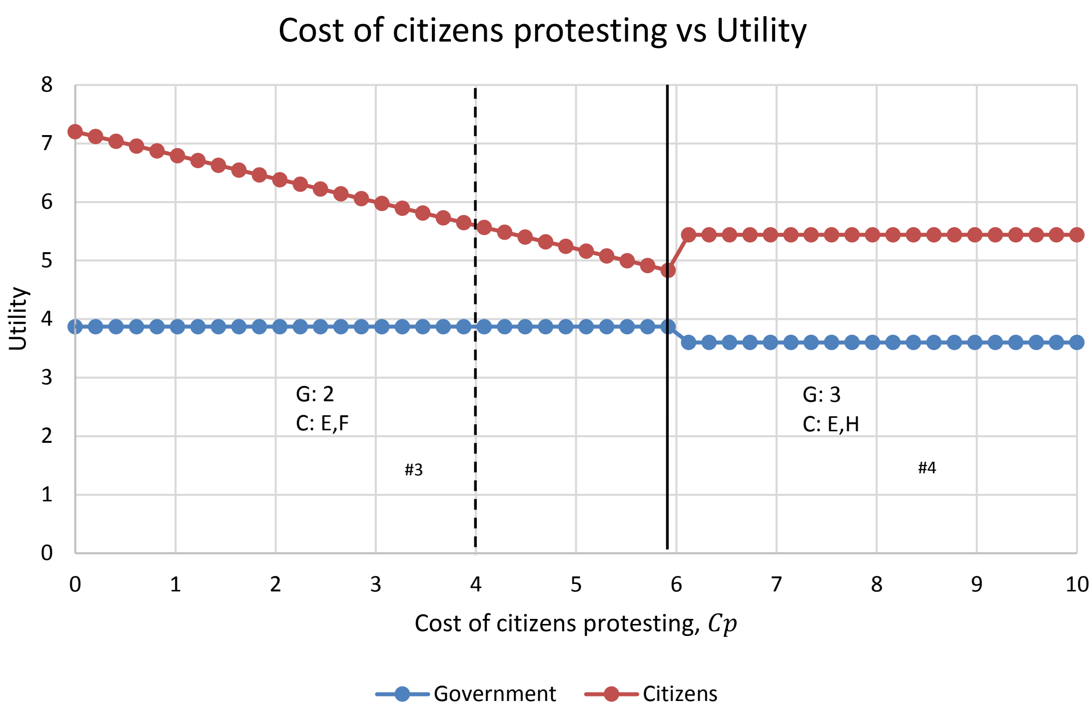

Figure 4.5: One-way Sensitivity Analysis with respect to Satisfaction Level of Citizens

From Figure 4.5, it can be observed that with a low cost of protest (C_p≤5.91), the government will execute the project regardless of the citizens' liking the proposal or not. If the citizens like the proposal, they do not protest, and if they dislike the proposal, they protest. But, with increase in the cost of protest (5.91<C_p≤10), the government changes its move to executing the project (in case the citizens like the proposal), or not executing it (in case the citizens dislike the proposal). In case the project is executed, the citizens will not protest, and in case the project is not executed, the citizens decide to seek improvements of the proposal.

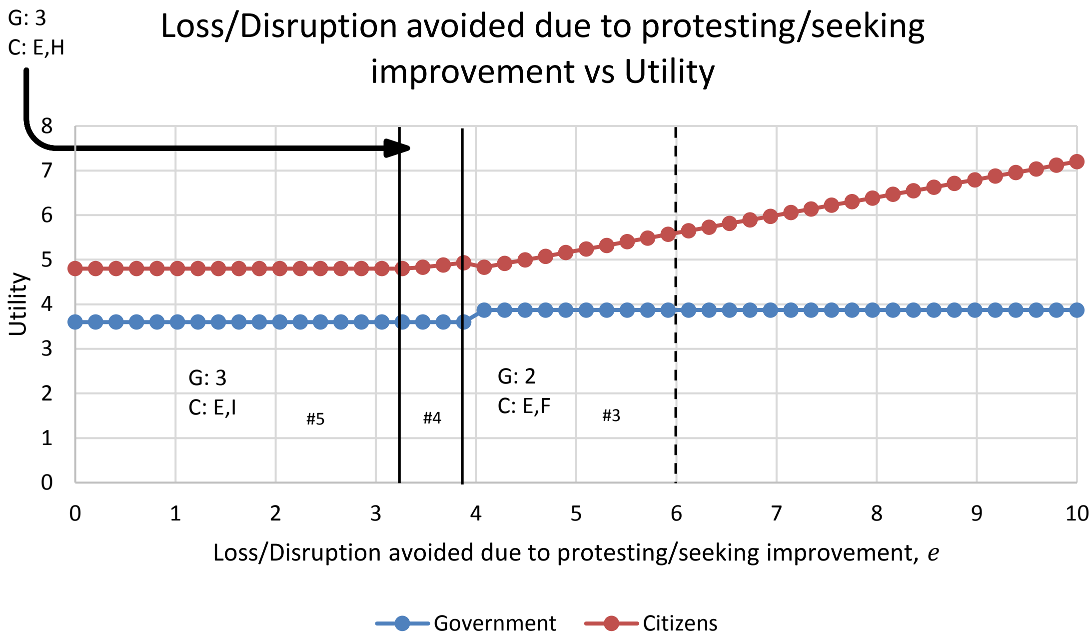

Figure 4.6: One-way Sensitivity Analysis with respect to Loss/Disruption avoided due to protesting/seeking improvement

From Figure 4.6, it can be observed that with a low loss avoided ($e \leq 3.26$) the government executes the project (in case the citizens like the proposal), or not executing it (in case the citizens dislike the proposal). In case the project is executed, the citizens will not protest, and in case the project is not executed, the citizens do not do anything. As the loss avoided increases ($3.26 < e \leq 3.88$), the government sticks with its move, but if the government does not execute the project at this level, the citizens will seek improvement of the proposal. As the loss avoided further increases ($3.88 < e \leq 10$), the government will execute the project regardless of the citizens' liking the proposal or not. If the citizens like the proposal, they do not protest, and if they dislike the proposal, they protest.

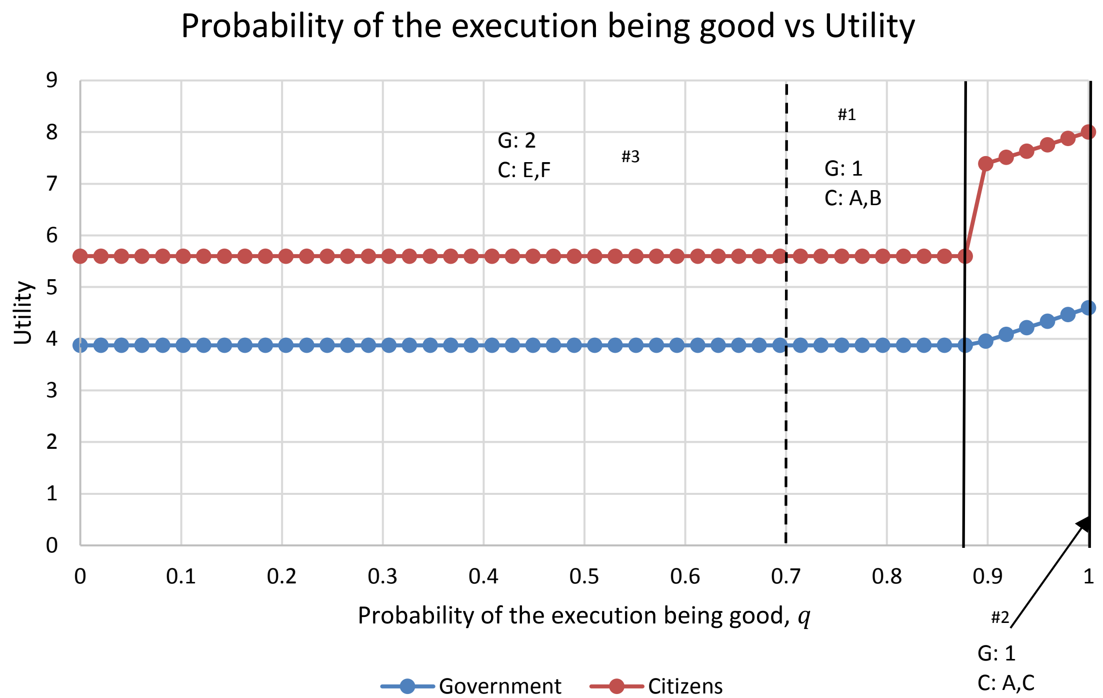

Figure 4.7: One-way Sensitivity Analysis with respect to the probability of the execution being good

From Figure 4.7, for a big range of the probability value ($0 \leq q \leq 0.877$), the government will execute the project regardless of the citizens' liking the proposal or not. If the citizens like the proposal, they do not protest, and if they dislike the proposal, they protest. When the probability of execution is relatively high ($0.877 \leq q < 1$), the government executes the project without considering the opinions of the citizens, and the citizens protest if the execution is bad. And with perfect probability ($q=1$), the citizens do not protest as the execution cannot be bad.

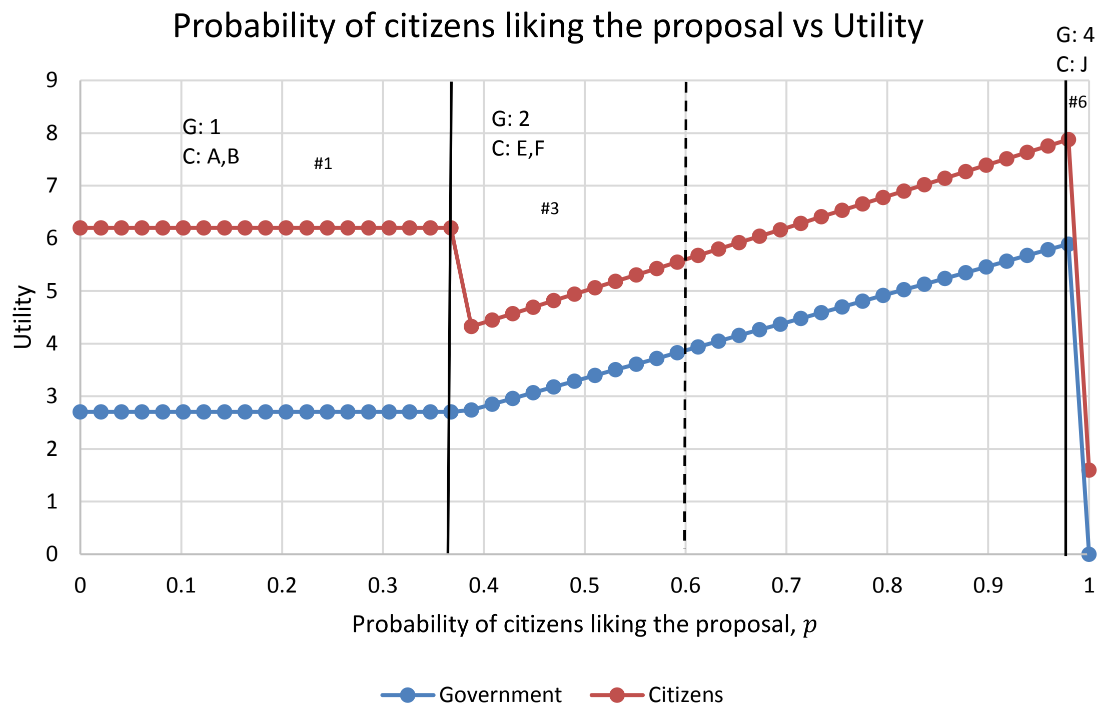

Figure 4.8: One-way Sensitivity Analysis with respect to the probability of the citizens liking the proposal

From Figure 4.8, with a low probability of the citizens liking the proposal ($p \leq 0.367$), the government executes the project without considering the opinions of the citizens, and the citizens protest if the execution is bad. For a significant part of increase of the probability ($0.367 < p \leq 0.97$), the government will execute the project regardless of the citizens' liking the proposal or not. If the citizens like the proposal, they do not protest, and if they dislike the proposal, they protest. When the probability of the citizens liking the proposal is very highly likely ($0.97 < p \leq 1$), the government does not do anything and the citizens seek improvements to initiate project ideas.

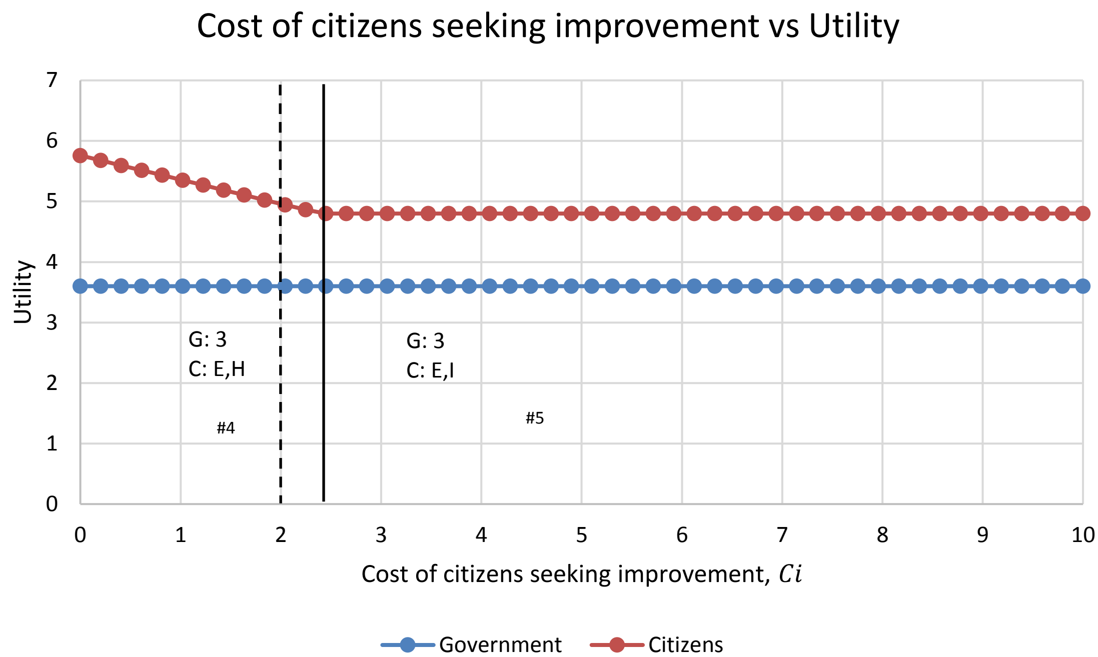

Figure 4.9: One-way Sensitivity Analysis with respect to the cost of citizens seeking improvement

From Figure 4.9, with low cost of seeking improvement (C_i≤2.44), the government's move is to execute the project (in case the citizens like the proposal), or not execute it (in case the citizens dislike the proposal). In case the project is executed, the citizens will not protest, and in case the project is not executed, the citizens decide to seek improvements of the proposal. When the cost of seeking improvement increases (2.44<C_i≤10), the government's move will be the same, but in the case of the government not executing the project, the citizens will do nothing.

Chapter 5

Conclusion and Future Work

Most of the smart city project planning is being done by the government, in any country in the world. The proposed model can be used and/or improved to initiate and accelerate strong citizen participation. The game tree includes possible ways of citizen participation in the decision-making process. There were a total of 9 parameters (without their extensions, for example, the extension of 'e' is 'e_1') which were varied. Each of these parameters were divided into 50 values on a scale of 0 to 10. One way sensitivity analysis was performed to observe the change in strategy of the government and the citizens with respect to the change in each parameter.

There are some limitations and suggestions that can be made in order to extend this work. This model is a single stage model and it can be extended to a multistage model, where the government makes further decisions based on the citizens' responses. A factor that can be included is time. There will be changes in the model with increase in time. For example, as time increases, the citizens' protest costs will increase in a multistage game. New payoffs and costs can also be added in the model to strengthen it.

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