Economic Analysis of Law Review

An Analysis of the Immediate Liability Law for Building Permits via the Principal-Agent Problem

Uma Análise da Lei de Responsabilidade Imediata para Alvarás de Construção por meio do Modelo do Principal-Agente

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RESUMO

A ineficiência no processo de obtenção do alvará de construção no Brasil pode se atenuada com a aprovação de novas leis que permitam uma relação de contraprestação de serviços entre o poder público e profissionais autônomos, em particular o Arquiteto. Um modelo do Principal-Agente é proposto para formalizar possíveis leis de Responsabilidade Imediata para licença de construção. A relação existente entre URB-Arquiteto é possível de ser formulada através da teoria dos jogos, e os resultados seguindo a políticas ótimas asseguram uma condição teórica das ações antes realizadas pelo setor público serem realizadas por parte dos profissionais liberais.

Palavras-chave: Teoria dos Jogos; Direito e Economia; Principal-Agente.

JEL: C7; K0

ABSTRACT

The inefficiency in the process of obtaining a building permit in Brazil can be mitigated with the approval of new laws that allow a relationship of consideration for services between the public administration and self-employed professionals, especially the architect. A Principal-Agent model is proposed to formalize possible Immediate Liability laws for building permits. The URB-Architect relationship can be formulated through the game theory, and the results following optimal policies ensure a theoretical condition of actions previously carried out by the public sector to be carried out by self-employed professionals.

Keywords: Game Theory; Law and Economics; Principal-Agent.

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1. Introduction

The inefficiency in the process of obtaining the building permit in Brazil is highlighted in Mello (2016). The data presented by the World Bank in the "*Doing Business 2019*" report can be used. The World Bank report is a series of studies to evaluate the regulations and procedures that improve business. Regarding the time to issue a building permit, Brazil ranks 175th among the 190 countries surveyed. The average time to obtain a building permit in Brazil is 434 days and the average number of procedures is 19.2 for the year 2018, unlike Hong Kong (China), which ranks first with an average time of 72 days and the average number of procedures equal to 11 (BANK, 2019).

The creation of laws, in public management, that aim to unbureaucratize or reduce the costs of the public machine is fundamental in the State's relations with society. The cities of Campina Grande, Fortaleza and Caruaru presented specific laws with the purpose of debureaucratizing the approval of building permits. These laws became known as Immediate Liability Approval - ILA, whose objective is the immediate approval of the building permit for small architectural projects.

Law and Economics can be observed as a course whose basis is classic microeconomics. The economic agents (companies, consumers, government) are positioned as decision-makers; the problems related to each agent can be described as optimization problems, and the objectives represented by a function to be maximized or minimized are subject to restrictions. One way to represent the existing relationships among the agents is the game theory, which by definition can be understood as: "a set of tools and a language to describe and predict the strategic behavior" (Picker, 1994).

The objective of this paper is to present an analytical model that allows the analysis of the existing relationship between the public administration through the Urbanization and Environment Authority - URB, responsible for issuing the building permit, and the technical manager for submitting projects for the construction of small enterprises, the Architect. In the request for release of the construction permit, the Architect is not necessarily the interested party or the one who makes the request, but for immediate release the process naturally begins with the Architect, since an architectural project must be produced. Although the norms for Immediate Liability Approval - ILA do not hold the Architect responsible alone, it is the Architect who indicates such a request. The URB-Architect relationship in the literature of game theory models is known as the Principal-Agent problem. The theoretical presentation of the Principal-Agent problem modeling is presented in the second part.

Traditional Principal-Agent model relationships are motivated by the Principal hiring the Agent, or the Agent is already a public servant and the Principal, who does not follow the Agent's job but observes its outcome, wishes to design a set of incentives for the Agent to carry out his job in the best way (Laffont & Martimort, 2020) (Salanié, 1997).

This paper does not present a theoretical innovation, but in the modeling construction there is a contribution in the sense that, unlike the already known models, the Agent can choose to use the release of a legal authorization granted by the Principal to the Agent as long as the Agent is responsible for complying with the legal rules in order to be entitled to the release. In Brazil, this relationship is regulated by the Immediate Liability Law.

In the third part, the Immediate Liability Approval – ILA for the cities of Campinas, Fortaleza and Caruaru are presented. The similarity among the laws in relation to the objective of reducing bureaucratization with social responsibility is achieved through the term of responsibility that the agents involved in the execution of the architectural project sign. These laws present punitive measures, and it is exactly the possibility of application of such restrictions that allows the formalization of the URB-Architect relationship through the Principal-Agent model. An analytical model is presented. The design of an analytical model allows theoretical results, being the usual way to apply the hypothetical deductive method. Thus, the hypotheses of the public manager's and of the architect's behavior are presented through conjectures, the consequences of the model being deduced through the differential calculation tool, with the consequences being observable, that is, validation by the agents' behavior.

Finally, in the conclusion, there are the results obtained by a hypothetical-deductive model as direct consequences of the hypotheses. Thus, the results are not questioned, but the hypotheses of the model are. The main expectation of the article is the contribution in terms of a research agenda that relates economic analysis and law theory with the use of the game theory.

2. Principal-Agent Model

Information economics has been a prominent area in recent years. The object of this study involves situations of information asymmetry. The main sets of economic models presented for information asymmetry are the moral hazard and adverse selection models.

The information asymmetry in the adverse selection models can be presented with a simple example. Consider an economy with perfect information, where the market representative agents know the quality of the goods that are offered. The used car market is a classic case of imperfect information. The buyer does not know if the car is a good car, with high quality, or a lemon, a low-quality car. The problem of adverse selection is described as a hidden information problem, i.e., one side of the market cannot observe the type or quality of the products on the other side of the market.

Another application is the agency theory, which has had considerable influence on the theory and practice of Public Administration. Its legacy has endured, with many policy designs continuing to be underpinned by concepts derived from the theory. The Principal's objectives are maximized, resulting in a more efficient and effective policy and service delivery outcomes, while the behavior of the Agent is stemmed and focused on the Principal' s goals via incentives and sanction (Gauld, 2016).

The moral hazard model refers to situations where one side of the market cannot observe the other one's actions. For this reason, the model is called the hidden action problem. There are several examples of the application of moral hazard in economic and legal relationships. A classic example is the insurance of assets, when it is not possible for insurance companies to observe the behavior of individuals. The habits of the insured party are not observed by the companies, that is, the relationship is hidden by the insured party. In private companies, more specifically in publicly traded companies, the shareholders have little or no information about the company managers' actions. In the examples above, there is a cost associated with monitoring the managers' or the insured party's actions. Thus, there is a need to design incentive mechanisms for the economic agents that carry out the hidden action in such a way that the well-being of the interested party in those actions reaches a satisfactory level. The information asymmetry illustrated by the moral hazard model creates the Principal-Agent relationship problem.

In this relationship, the **Agent** is defined as the acting person and his actions reflect directly on the **Principal**'s well-being. The problem arises when the Agent seeks his own objectives, which are different from the Principal's objective. Thus, the **Principal**'s problem is to design an incentive plan, s(x), that induces the **Agent** to take the best possible action from the **Principal**'s point of view (Varian, 1992).

The **Principal**'s gain is a function of the **Agent**'s effort in a certain activity. While the **Agent** tries to maximize his utility, which is a function of his effort (usually in a negative way, that is, the more the effort, the lower the **Agent**'s utility), it also depends on the established incentive plan, in this case, the higher the payment, the greater the **Agent**'s utility.

Formalizing the Principal-Agent problem is important for the understanding of the elements that should be considered in the application of a law's normatization or in the resolution that should be followed by public and private agents involved in public management issues in general. In the end, what is presented is a guide that can and should be studied before the application of the norm in order to verify the maximum of possibilities. A simpler formalization was chosen, where the **Agent** has only two action options: *b* for the best action for the principal and *a* for "alternative" actions. The result or product received by the **Principal** will be represented by *x*, in this case we are assuming that there is no uncertainty regarding *x*. The cost for the Agent to adopt a certain action will be represented by *c(.)*.

The gains of both **Principal** and **Agent** are represented by the theory of cardinal utility functions defined in the classic study by John von Neumann and Oscar Morgenstern, *Theory of Games and Economic Behavior* (1944). Through a simple representation of the model, one can define the utility functions for the **Principal** and the **Agent** respectively, such as: *x-s(x)* and *s(x) - c(a)*. The problem is to maximize the **Principal**'s utility function, subject to restrictions imposed by the **Agent**'s optimized behavior.

There are typically two restrictions involving the **Agent**: the first one guarantees a minimum gain for the Agent, a reserve utility $\bar{u}$, the objective being to guarantee the Agent's participation, which is why the restriction is called participation restriction (or individual rationality); the second restriction represents the possibility of incentive compatibility, the objective being to guarantee the possibility of influencing the **Agent**'s action. The Principal-Agent problem may present some variations; firstly, the Principal is the only one in the process, so the question now is to build the properties of the incentive policy, which is ideal from the Principal's point of view, so the Principal can be seen as a monopolist. In the second case, there is the possibility of multiple principals, in other words, it is a competitive market. In this paper, there is only one public agent that is represented by the principal; therefore, we will only consider the first case of a monopolist. Following the formulation presented by Varian (1992), the mathematical representation of the problem of designing (or projecting) an optimal incentive policy can be written as:

$$max_{b,s(.)} x(b) - s(x(b))$$

Subject to:

$$s(x(b)) - c(b) \geq \bar{u}$$

$s(x(b)) - c(b) \geq s(x(a)) - c(a)$, for every action belonging to the set of actions.

The first restriction is the participation restriction and the second one is the compatibility restriction. The resolution to the problem above can be obtained intuitively as Varian himself demonstrates (1992). The choice of the incentive policy, *s(x(b)),* considering the **Principal**'s objective function and the participation restriction, implies that the value of *s(x(b))* has to be as small as possible, considering that the sign is negative in the objective function, which implies that in the participation restriction there is equality, or as close as possible, s(x(b)) $= \bar{u} + c(b)$. An incentive policy for this case can be proposed as follows:

$$s(x*) = \begin{cases} \bar{u} + c(b*), & if\ x = x(b*) \\ -\infty, & otherwise \end{cases}$$

The incentive policy above is known as product-goal policy - if the Agent reaches the set goal, he receives his reservation price, otherwise the Agent has an extremely high punishment. The example was set to observe the need for knowledge of several elements of the **Principal-Agent** problem. In order to propose the solution, simplifications were considered, for example the Agent only had two possible actions.

There are two types of problems in developing incentive policies. Firstly, the Agents' actions are not properly observed by the Principal, the problem being known as the **hidden action** incentive problem. A second problem is that the Principal does not have perfect knowledge about the Agent's utility function, so in this case the information about the type of Agent is hidden to the Principal, the type of incentive problem being known as the **hidden information** problem.

2.1 Representation of the Principal-Agent Problem in the Form of Game Theory

An alternative way to present the Principal-Agent problem is through decision trees. The relationship among the agents undoubtedly forms a sequential decision process, where the decision of one influences the earnings or payoff of the other, that is, we face a game theory problem. The representation of sequential games for the Principal-agent problem in the case of complete information is shown in Figure 1.

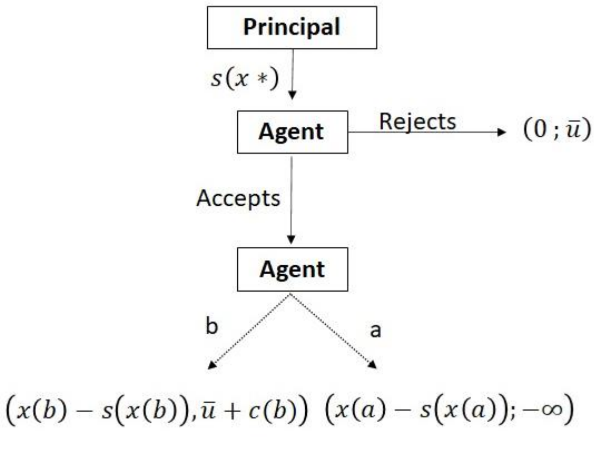


Figure 1 - Representation of the decision tree of the Principal-Agent game.

In the case of the representation of a **hidden action** problem, it is necessary to include a new player, called **nature**. Nature is a mechanism used to represent the uncertain actions in the decision process, there is no influence or decision by nature, there is no payoff attributed to nature. In the example above, the Principal does not specifically know which Agent's action is *b* or *a*, thus the introduction of this uncertainty is made through a probability distribution on the action, π. The probability distribution is typically an *a priori* or subjective distribution, resulting from a process of elicitation of experts' opinion, according to Campello de Souza (2007). The representation of the *a priori* distribution stems from a famous statistical theorem known as Bayes' theorem, named after Pastor Thomas Bayes, which is why incomplete information games are called Bayesian games.

Mathematically, the representation of the **hidden action** game is given by

$$max_{b,s(.)} \sum_{i=1}^{n} (x_i - s_i)\pi_{ib}$$

Subject to

$$\sum_{i=1}^{n} u(s_i)\pi_{ib} - c(b) \geq \bar{u}$$

$$\sum_{i=1}^{n} u(s_i)\pi_{ib} - c(b) \geq \sum_{i=1}^{n} u(s_i)\pi_{ia} - c(a)$$

The representation in the form of sequential game, in a simplified way, can be seen in Figure 2. The introduction of nature in the sequential game and of the *a priori* probability distribution π is fundamental to characterize the uncertainty about the agent's action.

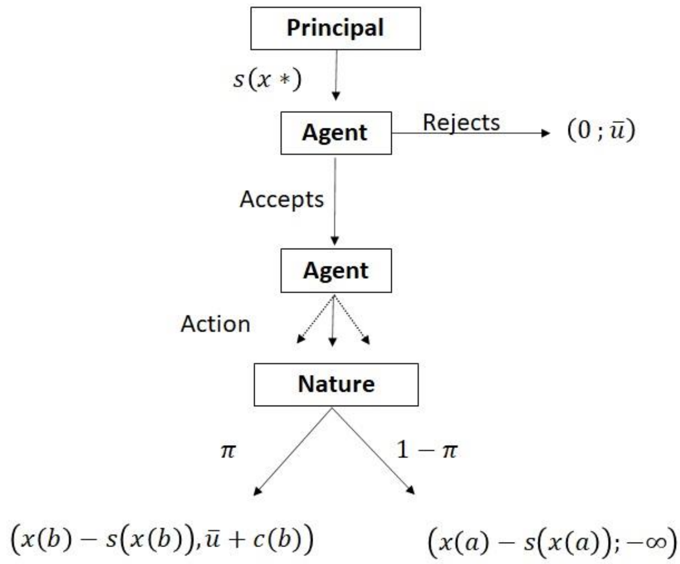


Figure 2 - Representation of the decision tree of the Principal-Agent game with hidden action.

The solution to the Principal-Agent's proposed problems with hidden action follows assumptions and specific representations of each problem; for example, the functional forms of the incentive mechanism and probability distribution can permit the use of one methodology or another. The objective so far has been to present the formulation; in general, the most representative methodology to obtain the solution are the Karush-Kuhn-Tucker first order conditions, or KKT conditions, in honor of the three mathematicians. A demonstration of the solution to the problem presented so far can be found in the book *Microeconomic Analysis*, by economist Hal Varian (Varian, 1992).

3. The Model to Immediate Liability Approval Law - ILA

The need for city planning encompasses several laws, including the Master Plan, Code of Works, Law of Land Use and Occupation, among others. One of the services demanded by the citizen to the municipal executive administration is the building permit. The building permit is the instrument that authorizes the citizen or company to undertake a construction job. A law that allows an immediate or quick issue of construction permits has been used by some cities in Brazil. Three laws will particularly be presented in this part.

In July 2015, the city of Fortaleza in the state of Ceará and the city of Campinas in the state of São Paulo approved, within days, two laws with the same principle. Law 10.391/2015 of July 7th, 2015 (Fortaleza, 2015) instituted the automatic construction permit. In Campinas, complementary law 110/2015 of July 13th, 2015 (Campinas, 2015) deals with the liable approval of projects for the construction of single-family buildings and small businesses. Thereafter, on December 27, 2018, the city of Caruaru in the state of Pernambuco instituted the law that regulates the procedure for expediting Immediate Liability Approval of construction projects of single-family, commercial and small institutional buildings – ILA, Law No. 6162/2018 (Caruaru, 2018).

The principle of the three laws is the same, transferring the responsibility of issuing a building permit to the professional in charge of elaborating the project. Although the laws deal with small constructions, one consequence is to unbureaucratize the process for approving a building permit for large construction works. However, the law presents more than just a debureaucratization process, there are elements that guide the relationship between the municipal administration and the professionals in charge of elaborating and requesting the approval of the project for construction. The process that exists in the law can be seen as a Principal-Agent problem.

The object of the three laws is the institutionalization of the building permit. Regarding time, it is evident that the laws of Fortaleza and Campinas have the same essence, but the writing and presentation of the concepts are done differently, making it clear that they were created at the same time, but with different wording. In the case of the law of Caruaru, the time gap enabled it to be created by observing the two previous laws.

The building permit issuing procedure becomes automatic as long as some hypotheses are observed and the process must follow the use of the necessary documentation. In Complementary Law No. 110/2015 of Campinas and No. 6162/2018 of Caruaru, the liability of the person in charge of the design of the construction project is clearly identified.

Laws No.10.391/2015 and No.6162/2018 have previous consultation as their object, while Campinas differently opted for not carrying out the previous consultation, which is an informative procedure with the objective of passing on to the interested party in the construction information about the land use and occupation, as well as the urban indexes.

There is a limitation regarding the types of projects that can be submitted to immediate approval for construction. The laws of Fortaleza and Caruaru are identical in relation to size, with areas of up to 750 m^2 and with restrictions in relation to other licenses, such as: environmental licensing, exemption from approval by the fire department, exemption from authorization or consultation with the Regional Air Command - COMAR, or that the property shall not be toppled or be in a toppling process. The municipality of Campinas restricts the Law of Liability Approval of Projects to Municipal Laws No. 6.031 of December 28th, 1988, No. 9.199 of December 2nd, 1996, and No. 10.850 of June 7th, 2001 (Campinas, 2015). The first one defines small-sized establishment "Art. 14. I – SMALL-SIZED ESTABLISHMENT: Establishment installed in an autonomous unit or commercial module, with a maximum private area of 500.00m² for commercial and service activities, and 1,000.00m² for institutional activities." (Campinas, 1988). Law No. 9.199 of December 2nd, 1996 deals specifically with the master plan of Barão Geraldo, a district of Campinas (Campinas, 1996). Law No. 10.850 of June 7th, 2001 creates the area of environmental protection and regulates the use of land occupation, as well as the exercise of activities by the public sector (Campinas, 2001).

The three municipalities establish sanctions and penalties in their laws. The set of sanctions and penalties can be understood as a process of negative incentives. The penalties and sanctions can be attributed to the person in charge of the project, as well as to the construction itself, since the permit can be cancelled (in this case the construction will be embargoed). The person in charge of the project may be prevented from submitting projects to the City Government, perhaps the greatest penalty for that person. However, the laws present a set of graduated penalties, that is, the process begins with a warning, going to a fine, to the imposition to change or undo what has already been done, to the seizure of machinery and assets, and finally the embargo or demolition of the building.

The observance of the set of negative incentives is precisely the normative application of a set of norms to discourage the non-fulfillment of the norms for the authorization of a construction.

The Immediate Liability Approval is a process of signaling attributions previously carried out by the public sector through the organ responsible for issuing the building permit to the private sector through the technician in charge of the construction work. The public organ is still responsible for issuing an enforceable license, while the responsibility for the compliance of the project is fully attributed to the representative of the private sector. The public organ will be called Urbanism Entity - URB, which is mostly the legal entity, and the technical representative will be simply called Architect. The Architect is entitled to participate or not in the ILA. The entity represents the Principal and the Architect, the Agent.

The adequacy of the project is represented by $E \in (0,1)$, the totally adequate project being $E = 1$, and otherwise when the project is totally inadequate $E = 0$. The number of projects to be submitted through Immediate Liability Authorization, N_{ARI}, is an Architect's decision. He must evaluate the quantity of processes that he will have to comply with and be inspected *a posteriori*.

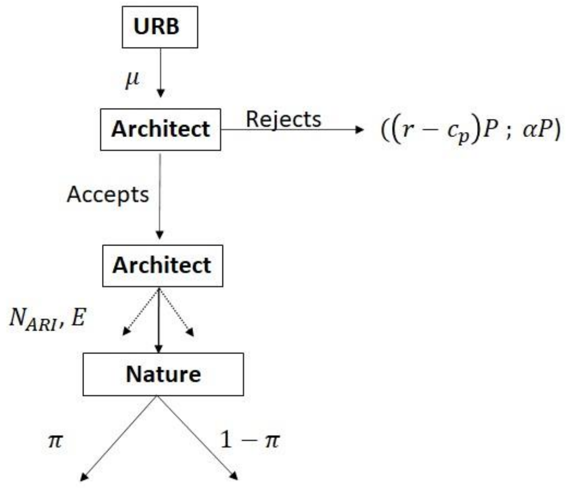
The decision of the Entity - URB is to design the necessary incentive mechanism for the Architect to participate in and execute the best projects without a social loss related to environmental, architectural and urban issues. The figure of social loss occurs when the low performance project is not identified and will be represented by $-S$. The architectural projects have parameters that represent desired and necessary characteristics for the resolution of urban and environmental issues, among others. The need for a percentage of natural land, for example, is a parameter to avoid environmental and urban impacts, preventing heating and possible floods.

The incentive mechanism, μ, represents the punishment the Architect will be given by the URB for the indication of Authorization projects of non-compliance Immediate Liability. The financial gains that the Architect earns are represented by parameters α and γ, the former being the minimum gain by the submission and approval of a standard model project, *P*, while the latter represents an extra gain for the immediate liberation to proceed with the construction work.

For every project submitted, the URB receives the amount of r and has a cost to evaluate these projects represented by c_p. The inspection process of all licensed projects through the Immediate Liability Authorization would precisely correspond to the standard evaluation carried out. The inspection cost decreases with the number of processes submitted by the ILA. It is known that $P = N + N_{ARI}$, where N is the number of cases submitted by standard assessment processes other than the ILA.

The implementation of a random inspection system with the objective of not only reducing costs, but also allowing an increase in the speed of project liberation is the central objective of the design of this incentive mechanism. The representation of Nature in the game is exactly this random inspection mechanism, the probability of finding an Authorization project of Immediate Liability in non-compliance with the norms being represented by π. A possible representation for the probability distribution is $\pi = 1 - E$, following the example of the simplified Moral Hazard model in the labor market presented in Bierman & Fernandez (2010).

The Architect will eventually be punished with a fine, μ, whereas the expected amount for such payment will depend on the probabilistic mechanism, π, and of the number of projects submitted for Immediate Liability Approval, $\mu\pi N_{ARI}$. Considering the possibility of financial gain of the same amount by the URB, the Moral Hazard problem between the URB-Architect could be defined. However, it can and should be questioned whether it is not possible for a more impacting and therefore more impeding incentive policy to be conceived. One way to evaluate this is to establish a functional form different from the average amount received by the URB for the discovery of non-compliant projects. Hence, what is the appropriate functional form? Mathematically, it is possible to represent this expected gain for the discovery of projects that are not in compliance by $\pi N_{ARI}\mu^{a}$, a being the parameter that potentializes the URB's gain for the incentive policy.



$$\left(rP - c_p(P - N_{ARI}) + \pi N_{ARI}\mu^{a}; \alpha P + \gamma N_{ARI} - \mu\pi N_{ARI}\right)\left(rP - c_p(P - N_{ARI}) - S;\ \alpha P + \gamma N_{ARI}\right)$$

Figure 3 - Representation of the decision tree of the URB-architect game.

The Principal-Agent problem between the URB and the Architect can be summarized in Figure 3. The URB establishes an incentive mechanism, and the Architect decides whether to accept the possibility of submitting projects by signing the Immediate Liability Authorization. If accepted, he chooses the number of submitted projects and the effort needed to adapt the project. The optimal conditions for solving the problem of URB-Architect are in Annex I.

By using the retroactive induction process, the URB knows the answer that the Architect will give based on the incentive policy. The optimal solution to maximize the Architect's expected amount is given by the following relationship:

$$E^{*} = 1 - \sqrt{\frac{\alpha + \gamma}{\mu}}$$

The relationship evaluation is this: if the financial gain, α and γ, for the architect increases, his effort decreases; if the punishment for non-compliant projects, μ, increases, the effort decreases. The number of processes submitted for Immediate Liability Authorization, N_{ARI}, does not present an explicit relationship in optimal conditions. Thus, its determination is made exogenously to the model, by choice of each Architect.

Knowing the Architect's strategy, the URB establishes an incentive policy that seeks to maximize the URB's expected utility. The optimal incentive policy is a fine for architectural non-compliance of the projects. The URB's optimal incentive policy is given by the following formula:

$$\mu^* = \left(\frac{S(\alpha+\gamma)^{1/2}}{(a-1)N_{ARI}}\right)^{\frac{2}{2a-1}}$$

The URB is to increase the amount of the fine based on the Architects' financial gains, $(\alpha + \gamma)$; likewise, the fine must be higher if the social, environmental and architectural loss, S, increases. The fine decreases if the number of processes submitted through the Immediate Liability Approval increases. Finally, the main result regarding the establishment of incentive policies is that the parameter that potentializes the URB's gain by means of the incentive policy, a, must necessarily be higher than 1.

4. Conclusion

The objective of the model presented in this paper is the formalization of the Immediate Liability Approval law through a Principal-Agent model. Some characteristics of the law have not been incorporated to the model, such as the notification of non-compliance warnings, the possibility of extreme punishment with the 12-month suspension of the Architect's activities, or even the possibility of a deadline for regularization. However, the model allows for new considerations that can be incorporated into the administrative process, for example, the fine should take into account aspects such as the number of processes submitted and the amount of financial gains to the Architects.

The formalization of laws through models that incorporate the functional forms of the agents involved should permit greater effectiveness of laws in relation to their objective, allowing for a research agenda in the legal and social spheres. For example, the clear question posed by the Immediate Liability Approval laws of the three cities is whether the number of projects submitted for immediate approval has increased; if not, other questions may be raised: what is the cause for the Architect not to submit projects for Immediate Liability Approval? Is there any flaw in the law or any social or cultural characteristic on the part of the Architects that implies the non-use of the law?

Finally, it is believed that multidisciplinary research projects in the legal area based on game theory, which is a mathematical theory that has been used for years by other social sciences, mainly in economics and sociology, can and should be used in the legal area.

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APPENDIX I - Optimality Conditions for the URB-Architect Problem

a. First order conditions for the Architect

Architect's gain if the process is found to be inadequate:

$$A^D = \alpha P + \gamma N_{ARI} - \mu\pi N_{ARI} \quad (1)$$

Architect's gain if the process is not found to be inadequate:

$$A^{ND} = \alpha P + \gamma N_{ARI} \quad (2)$$

Architect' s expected amount:

$$VEA = \pi A^D + (1-\pi)A^{ND} \quad (3)$$

$$VEA = \pi[\alpha P + \gamma N_{ARI} - \mu\pi N_{ARI}] + (1-\pi)[\alpha P + \gamma N_{ARI}] \quad (4)$$

$$VEA = \pi\alpha P + \pi\gamma N_{ARI} - \mu\pi^2 N_{ARI} + \alpha P + \gamma N_{ARI} - \pi\alpha P - \pi\gamma N_{ARI} \quad (5)$$

$$VEA = \alpha P + \gamma N_{ARI} - \mu\pi^2 N_{ARI} \quad (6)$$

It is known that $P = N + N_{ARI}$; replacing it in equation (6), we have:

$$VEA = \alpha N + \alpha N_{ARI} + \gamma N_{ARI} - \mu\pi^2 N_{ARI} \quad (7)$$

By deriving the expected amount in relation to the number of processes submitted through the Immediate Liability Authorization, N_{ARI}, we have:

$$\frac{\partial VEA}{\partial N_{ARI}} = \alpha + \gamma - \mu\pi^2 = 0 \quad (8)$$

$$\pi^2 = \frac{\alpha + \gamma}{\mu} \quad (9)$$

$$\sqrt{\pi^2} = \sqrt{\frac{\alpha + \gamma}{\mu}} \quad (10)$$

$$\pi = \sqrt{\frac{\alpha + \gamma}{\mu}} \quad (11)$$

It is known that $\pi = 1 - E$; replacing it in equation (11), we have:

$$E^* = 1 - \sqrt{\frac{\alpha + \gamma}{\mu}} \quad (12)$$

Considering VEA a result of the effort to adapt to project E, knowing that $\mu(E)$ is a function of E, and $\pi = 1 - E$, we have then:

$$VEA = \alpha P + \gamma N_{ARI} - \mu(E)(1-E)^2 N_{ARI} \quad (13)$$

By deriving the architect's expected amount with regard to the effort of adaptation to project E, we have:

$$\frac{\partial VEA}{\partial E} = -[-2N_{ARI}(1-E)\mu(E) + N_{ARI}(1-E)^2 \frac{d\mu(E)}{dE}] = 0 \quad (14)$$

$$2N_{ARI}(1-E)\mu(E) = N_{ARI}(1-E)^2 \frac{d\mu(E)}{dE} \quad (15)$$

$$\frac{\frac{d\mu(E)}{dE}}{\mu(E)} = \frac{2}{1-E} \quad (16)$$

Equation (16) is a first order differential equation of separate variables, which can be solved by simple integration:

$$\int \frac{1}{\mu} d\mu = \int \frac{2}{1-E} dE \quad (17)$$

$$\ln(\mu) + c_1 = -2[\ln(1-E) + c_2] \quad (18)$$

$$e^{\ln(\mu)+c_1} = e^{-2[\ln(1-E)+c_2]} \quad (19)$$

Considering $e^{c_1} = A_1$ and $e^{-2c_2} = A_2$ integration constants, we have:

$$\mu A_1 = \frac{A_2}{(1-E)^2} \quad (20)$$

For the sake of simplification, we will consider $\frac{A_1}{A_2} = k$, and equation (20) can be rewritten as:

$$(1-E)^2 = \frac{1}{\mu k} \quad (21)$$

$$\sqrt{(1-E)^2} = \sqrt{\frac{1}{\mu k}} \quad (22)$$

$$E^* = 1 - \sqrt{\frac{1}{\mu k}} \quad (23)$$

By equating the two necessary conditions for the Architect's optimum, that is, equations (12) and (23), we have the integration constant:

$$k = \frac{1}{\alpha + \gamma} \quad (24)$$

The Architect's optimization policy in relation to the URB incentive policy will be given by equation (12):

$$E^* = 1 - \sqrt{\frac{\alpha + \gamma}{\mu}}$$

b. First order conditions for the URB

The URB's gain if the process is found not to be adequate:

$$U^D = rP - c_p(P - N_{ARI}) + S + \pi N_{ARI}\mu^a \tag{25}$$

The Architect's gain if the process is not found to be inadequate:

$$U^{ND} = rP - c_p(P - N_{ARI}) - S \tag{26}$$

The URB's Expected Amount:

$$VEU = \pi U^D + (1-\pi)U^{ND} \tag{27}$$

$$VEU = \pi[rP - c_p(P - N_{ARI}) + S + \pi N_{ARI}\mu^a] + (1-\pi)[rP - c_p(P - N_{ARI}) - S] \tag{28}$$

$$VEU = \pi(rP - c_p(P - N_{ARI})) + \pi S + \pi^2 N_{ARI}\mu^a + rP - c_p(P - N_{ARI}) - S - \pi(rP - c_p(P - N_{ARI})) + \pi S \tag{29}$$

$$VEU = 2\pi S + \pi^2 N_{ARI}\mu^a + rP - c_p(P - N_{ARI}) - S \tag{30}$$

Considering $\pi = 1 - E$, and for the application of the retroactive induction process, it is necessary to apply the Architect's optimality condition to the URB's objective function, we have:

$$\pi = 1 - E^* \tag{31}$$

$$\pi = 1 - 1 + \sqrt{\frac{\alpha + \gamma}{\mu}} \tag{32}$$

$$\pi^* = \sqrt{\frac{\alpha + \gamma}{\mu}} \tag{33}$$

Substituting equation (33) in equation (30), we have:

$$VEU = 2\sqrt{\frac{\alpha+\gamma}{\mu}}S + \frac{\alpha+\gamma}{\mu}N_{ARI}\mu^a + rP - c_p(P - N_{ARI}) - S \tag{34}$$

$$VEU = 2S(\alpha+\gamma)^{1/2}\mu^{-1/2} + (\alpha+\gamma)N_{ARI}\mu^{a-1} + rP - c_p(P - N_{ARI}) - S \tag{35}$$

By deriving the expected amount in relation to the URB's incentive mechanism μ, we have:

$$\frac{\partial VEU}{\partial \mu} = 0$$

$$\frac{\partial VEU}{\partial \mu} = -S(\alpha+\gamma)^{1/2}\mu^{-3/2} + (a-1)(\alpha+\gamma)N_{ARI}\mu^{a-2} = 0 \tag{36}$$

$$\mu^{a-1/2} = \frac{S}{(a-1)(\alpha+\gamma)^{-1/2}N_{ARI}} \tag{37}$$

The optimal incentive mechanism is given by:

$$\mu^* = \left(\frac{S(\alpha+\gamma)^{1/2}}{(a-1)N_{ARI}}\right)^{\frac{2}{2a-1}} \tag{38}$$