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Modeling the green building (GB) investment decisions of developers and end-users with transaction costs (TCs) considerations

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ABSTRACT

The paper, through a "regenerative" lens, has focused upon a new conceptual game system involving transaction costs (TCs) for creating a more accessible green buildings (GB) market. Individual stakeholders steadfastly guard their own interests in any investment decision, which seldom considers any positive gains to society. Green buildings, branded as partial public goods, involve rational and irrational factors, incurring extra transaction costs (TCs) and affecting the willingness of the stakeholders to take part. This paper examines how to reduce the TCs incurred during the game played in the decision-making process with the ultimate aim of promoting GB. In the game model, the developers and end-users negotiate and bargain over the TCs caused by GB in comparison with its conventional counterpart. The findings are that 1) TCs are the overriding barriers impeding the development of the GB market. Reducing TCs will facilitate supply and demand in the GB market; 2) the equilibrium payoffs for the developer and the end-user are proportional to their bargaining powers (the higher the bargaining power is, the more benefit it will gain from the GB transaction); 3) strengthening the bargaining power of the developer can increase the expected utility of developing GB; and 4) more fake GB products or less credible developers will result in higher TCs for the end-users and therefore lower payoffs will be expected. The findings stress that the choice between developers & end-users over investing in GB is a complex game problem, where TCs could be conceptualized and showed their important role. By minimizing the TCs incurred in the complex decision of GB, it will not only benefit themselves but also bring net regenerative outcomes to society.

1. Introduction

"Regenerative development" (Reed, 2007; Mang, 2009; Du Plessis, 2012) and "positive development" (Birkeland, 2008) is to improve the capacity of the support system to make best use of the resources and improve society's well-being in a way that leads to future qualitative growth. The question in regenerative development is "How can we solve this problem in such a way that we improve the capacity of the underlying support system?" Regeneration includes a deep search and understanding on the nature of the relationship between human and earth systems (Reed, 2007). It values the input from all stakeholders and hope the information as transparent as possible so that everyone can see how they win and what they might need give up to gain a greater good. Regenerative development sees the potential needs and problems as markets for social and economic entrepreneurs, and utilizes design that can do more with less. It is focused on the vision of what is desired, not what is expedient (Gabel, 2009).

Instead of doing less damage to the environment, which is stated in the definition of "sustainability," it is necessary to explore how one can participate with the environment by shifting the fragmented system into an integrated one and study the living system interrelationships (Reed, 2007). Green buildings have generally been recognized as technical contributors to achieve urban sustainability. From the perspective of a "regenerative" lens, we need go beyond the observable status to look for further improvement that make the overall output is greater than or equal

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to the input. For delivering GB and forming a new GB market system, there are extra factors, both rational and irrational, incurring TCs and affecting the willingness of the stakeholders to take part in GB investment. The paths for research have reframed GB practices to look for "win–win" solutions and to seek for a net positive gain from GB, by considering the intangible societal costs.

Green building is branded with characteristics that are associated with public goods. With positive externalities, social returns in the GB investment are larger than the private returns of the stakeholders. Considering the difference between private and social gains, there is the extra perspective of bringing positive externalities in promoting GB, by looking into a new concept of economic system involving TCs. The stakeholders, such as the developers and end-users, will focus on their private returns. Careful reading of the decision-making of GB transaction to be successfully reached, taking TCs into consideration, enables us to develop mental maps of leverage points, at where small incentives/intervention from the government can easily energize the GB market system as a whole to cut overall tangible and intangible costs and reveal the positive gain of GB.

This study examines how to smooth transactions for the key GB market stakeholders and help them lessen the TCs involved in GB transactions, in order to promote GB more effectively and bring net positive outcomes to society. The developers and end-users' concerns and their interactions with GB investment are scrutinized and modeled upon reaching the final decisions, with TC considerations. It highlights positive externalities in GB investment with social returns larger than private returns of the two stakeholders. It explains theoretically that TCs should not be neglected in GB studies and that, by taking TCs concerns seriously, it is a leverage point to making both the GB market welcome and the government policies favorable.

The TCs game modeling for GB market will cover the following aspects:

- Understanding the pattern of decision-making to achieve GB transactions.
- Translating the patterns into desires/expectations/concerns that affect the decision-making concerning GB by key stakeholders.
- Confirming the existence of TCs in affecting GB transactions. The TCs game modeling framework provides ongoing feedback: a conscious process of learning and participation through action, reflection and dialog.

The TC game modeling of this study aims to ensure that considerable investment achieved by development of GB yields more than just realizing the physical transaction of GB with more deployment of green technology. It is hoped to improve the efficiency in the decision-making processes of GB investment and transaction between developers and end-users, by doing so to enable greater influences of effectiveness in market incentives or intervention from the government. It also discusses how to create mutually beneficial relationships considering TCs and other hidden factors in GB system.

To achieve the above overall aim, the specific objectives of this paper are (i) to explore and compare the games between developers and end-users on their GB investment in scenario with and without the consideration of TCs (how TCs affect game decision-making), (ii) to examine how the uncertainty as the important aspect of TCs affect the game of decision-makings between the two parties (iii) to discuss and propose the action points, or policy implication with a better understanding of the TCs in GB system.

2. Literature review

2.1. The context of game between the developers and end users

Green building is part of the real estate market. In general, the real estate market is "the sum of real estate transactions" and "the bridge connecting real estate development and construction to final consumption, as well as the economic process where the value in use and value of real estate are realized" (Gao, 2004). It is characterized by some special features different from the common market, including "localized transactions, oligopoly competition, supply lag, diverse demands, investment or speculation, complex transactions, constrained by finance, government intervention and inefficiency" (Qiao, 2001; Zhang et al., 2011). From the perspective of game theory, the game of the transaction is complicated between the end-users and developers in the following ways: (1) information asymmetry is severe; (2) severe inequality in the bargaining power of the developers and end-users exists during the market transaction; (3) there are lots of external factors, such as uncertainty, influencing the players' strategies apart of the concerns of the buildings' energy performance; (4) energy efficiency performance of real estate is not always the focal point in the game between the developers and the end-users (for details please refer to Qian, 2012).

Game theory is rendered mathematically and logically to analyze the interactions between stakeholders from a micro analyses perspective. It helps to better understand the underlying mechanism and essence of the market and thus provides a sound rationale for policymakers. Many studies have been applying game theory to explain and analyze phenomena in the field of building energy efficiency and GB development (Zhang, 2004; Shang and Du, 2005; Zhou, 2006; Sun et al., 2009).

Real estate developers who initiate building projects and the end-userqs who create the market demand and eventually receive the final product are the two dominant forces in building market and thus form the core study objects of this research. As most incentive schemes are voluntary and market-based, the stakeholders involved are free to adapt or avoid them based on their private interests. It is rational to build up a game model between developers and the end-users and simulate their mind in scenarios to see, how the decision-makings are made on investing in GB with TCs considered, and how the incentives to be better designed that bring about successful GB investment.

The proposed model gives assumptions that fit well to the nature of the real estate market in practice. Firstly, the transaction of GB at the micro level is actually happening between one developer and one end-user, negotiating over the price for each given real estate separately. Secondly, the whole GB market can be abstractly deemed as the game between a hypothetical real estate developer and a hypothetical end-user, representing the aggregate supply and demand respectively. The equilibriums in the game are the total quantity of GB developed in market and the average price of GB. Thirdly, the game model can provide the foundation to further simulate the interactions in the GB market by considering the probability distributions of the developers and the end-users. Lastly, the hypothetic game model has a clear definition about the payoffs of GB, avoiding the unnecessary concerns and discussions about utilities from other improvements, such as property appreciation or comfort improvement, and the differences among countries, regions or development stages, making the conclusion more generic and applicable.

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2.2. TCs in the game between the developers and the end users

A transaction is a process by which a good or service is transferred across a technologically separable interface (Williamson, 1975, 1985). As the market in reality is often inefficient (e.g., information asymmetry) and uncertain (e.g., product and process uncertainty), in order to process a transaction, customers must conduct activities such as searching for information, negotiating terms, and monitoring the on-going process to ensure a favorable deal (Coase, 1937). The costs involved with such transaction-related activities represent TCs. In other words, the total customer cost includes the buyer's time, energy, psychic cost and others. The buyer evaluates these elements together with the monetary cost to form a total customer cost (Chen, 2006).

Based on Williamson's framework (Williamson, 1975, 1985), there are two cost components in any contract relationship: the ex ante and ex post costs. The ex ante costs are those associated with negotiating and establishing a contract. Part of these costs grow from extensive information gathering. A more pervasive and threatening source of ex ante costs is boundary rationality. Ex post costs are the actual, in contrast to expected, growth in prices borne by one or both members of a coalition after the contractual relationship has been forged. Williamson (1985) includes among ex post costs "the mal adaption costs incurred when transactions drift out of alignment in relation to [previous expectations], … the haggling costs incurred if bilateral costs are made to correct ex post misalignments, … the setup and running costs associated with the governance structures to which disputes are referred, and … the bonding costs of effecting secure commitments." More importantly, ex post and ex ante costs are interrelated. This interrelation leads to the pervasive risk of opportunism: the feature of human nature that causes people either to fabricate or to withhold critical cost-bearing information to another party.

2.3. Limitations of a game theory perspective

One of the limitations of a game theory perspective is the assumption that atomized players are not able to co-operate or learn from each other. There is literature in economic sociology that addresses the problems of uncertainty in the market through the notion of social embedding (Granovetter, 1985). Buyers and developers do not need to search for and process all relevant information because this information is socially shared; buyers and developers with bounded rationality can follow the lead of others. There are limitations to this since developers and users are idiosyncratic, but still this is how agents operate in the real world (Biggart and Lutzenhiser, 2007). This is beyond the scope and paradigm of game theory and addressed as a limitation of the study.

3. Presenting the game model between the developers and end-users

Researchers in the building field have been applying game theory to explain and analyze a wide array of phenomenon in the field of building energy efficiency and GB development (Zhang, 2004; Shang and Du, 2005; Zhou, 2006; Sun et al., 2009). The authors (Qian and Chan, 2011; Qian et al., 2011; Qian, 2012) have also proposed a game model of the GB market with TC considered in a two-developers setting, pursuing maximum profits in developing GB and competing in a localized market. In this study, a game model is considered between the developers and the end-users with respect to GB. In a general sense, "a transaction cost is incurred when an economic exchange happens between two or among more parties, it thus must come from a game behavior. When there are a lot of parties involved, the game behavior approaches general equilibrium. Therefore, game theory is much more generic than general equilibrium analysis (Wang, 1995). The problem is how to frame the game model exclusively on GB, rather than having it affected by other unrelated factors. For example, the price of the real estate may be affected by its energy efficiency performance, as well as other factors such as location, layout, macroeconomic condition, etc. Instead of including all the general features of the real estate market, our objective is to investigate the main barriers in terms of TCs prohibiting the development of GB.

Suppose for the developer, the extra cost needed to develop GB is C; for the end-user, the additional utility brought from purchasing the GB is V, and V > C. The developer and the end-user are negotiating about the price P for GB. For simplicity, we assume the cost to develop a conventional building product and the utility from purchasing it are both 0. Suppose these presumptions are common knowledge for the developer and the end-user. To solve the equilibrium in the game model, we regard it as a problem to fairly allocate the extra benefits brought by the GB between the developer and the end-user. As long as the GB is economically and technically feasible, both the developer and the end-user can mutually benefit from the transaction of the GB product, only negotiating over exactly how to reach it.

The negotiation process has been modeled using bargaining theory, which is a natural framework that allows us to simulate the game between the developer and the end-user with respect to GB from the micro point of view. Bargaining theory, introduced by Nash (1950, 1953), postulates a group of players choosing a payoff allocation from a set of feasible payoff allocations. The implementation of a payoff allocation requires unanimous agreement among the players. In the case of disagreement, the players end up getting some predetermined payoff allocation known as the status quo or the threat point. A bargaining solution is defined on class bargaining problems, assigning a feasible payoff allocation to each bargaining problem (Qin, 2009).

A two-person bargaining problem is composed of a choice set $S \subset R^2$ of feasible payoff allocations the players can jointly achieve with agreement, and a threat point $d \in S$ the players end up getting in the case of disagreement. A bargaining solution on a class B of bargaining problem is a rule f assigning a feasible allocation $f(S, d) = (f_1(S,d), f_2(S,d)) \in S$ to each bargaining problem $(S,d) \in B$.

A positive affine transformation for player i's payoff is a mapping $\tau_i : R \to R$ such that for some two real numbers $a_i > 0$ and b_i, $\tau_i(u_i) = a_i u_i + b_i$ for all $u_i \in R$. Given τ_1 and τ_2, $\tau(u) = (\tau_1(u_1), \tau_2(u_2))$ for all $u \in R^2$.

Nash (1950, 1953) considered the following well-known axioms on bargaining solutions.[1]

- *Strictly Individual Rationality (SIR)*: *For any* $(\mathbf{S},\mathbf{d}) \in \mathbf{B}, \mathbf{f_i}(\mathbf{S},\mathbf{d}) > \mathbf{d_i}$, $\mathbf{i} = 1,2$.
- *Symmetry (SYM)*: *For any* $(\mathbf{S},\mathbf{d}) \in \mathbf{B}$ *with* $\mathbf{d}_1 = \mathbf{d}_2$ *and* $(\mathbf{u}_2,\mathbf{u}_1) \in \mathbf{S}$ *whenever* $(\mathbf{u}_1,\mathbf{u}_2) \in \mathbf{S}, \mathbf{f}_1(\mathbf{S},\mathbf{d}) = \mathbf{f}_2(\mathbf{S},\mathbf{d})$.
- *Invariance to Equivalent Utility Representations (INV)*: *For any* $(\mathbf{S},\mathbf{d}) \in \mathbf{B}$ *and for any positive affine transformation* $\tau : \mathscr{R}^2 \to \mathscr{R}^2 \; \boldsymbol{f}(\tau(\boldsymbol{S}), \tau(\boldsymbol{d})) = \tau(\boldsymbol{f}(\boldsymbol{S}, \boldsymbol{d}))$
- *Independence of Irrelevant Alternatives (IIA)*: *For any* $(\mathbf{S},\mathbf{d}), (\mathbf{S}^1,\mathbf{d}) \in \mathbf{B}$ *with* $\mathbf{S} \subseteq \mathbf{S}^1$, $\mathbf{f}(\mathbf{S}^1,\mathbf{d}) \in \mathbf{S}$ *simplies* $\mathbf{f}(\mathbf{S},\mathbf{d}) = \mathbf{f}(\mathbf{S}^1,\mathbf{d})$.

When B is composed of compact convex bargaining problems with strictly Pareto dominated threat points, these four axioms

[1] Roth (1979) showed that a bargaining solution is strictly Pareto optimal whenever the solution satisfies SIR, INV, and IIA. Thus, with INV and IIA, Pareto optimality, as Nash originally considered, can be replaced by SIR.

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uniquely characterize the symmetric Nash Bargaining solution: to each (S,d) ∈ B it assigns the payoff allocation determined by

$$\max_{u\in S,\ u\geq d}(u_1-d_1)(u_2-d_2)$$

See Nash (1953) and Roth (1979) for details.

When the symmetry axiom is removed, Kalai (1977) showed that for the class of compact convex bargaining problems, the bargaining solution that assigns the payoff allocation determined by the maximization of the Nash product weighted by bargaining powers α for player 1 and $1-\alpha$ for player 2 is

$$\max_{u\in S,\ u\geq d}(u_1-d_1)^{\alpha}(u_2-d_2)^{1-\alpha}$$

4. Modeling the GB investment decisions between the developers and the end-users

4.1. Game model between the developers and end-users without TCs

Suppose the developer and the end-user are negotiating in a perfect market with zero TCs, implying that the information is perfect for each party, without any searching, negotiating, contracting, monitoring and enforcement costs in terms of time, effort, money and risk. Thus, payoff to the developer can be expressed as the profit (price minus cost) and payoff to the end-user can be expressed as utility minus price. In the scenario without TCs, if benefit of the GB exceeds its cost (V > C), obviously, the rational developer and the rational end-user will make an agreement upon the price through bargaining (V ≥ P ≥ C), both with positive payoffs in the equilibrium. That is, the developer will develop the GB product, and the end-user will purchase it at price P.

According to the Nash Bargaining Theory (1950), solving the equilibrium price of GB agreed between the developer and the end-user in the market can be expressed as solving the optimization problem, given by

$$\max_{P} Q=(P-C)^{\alpha}(V-P)^{1-\alpha}$$

where Q represents the aggregated payoff of the developer and the end-user. Let $Q_D = P - C$ denote the payoff for the developer by developing the GB product. Let $Q_C = V - P$ denote the payoff for the end-user by purchasing the GB product. α and $1-\alpha$ represent the bargaining powers for the developer and the end-user respectively.

Proposition 1. *The equilibrium price of the GB product, the Nash bargaining solution in the game model between the developer and the end-user without TCs, is given by:*

$$P^{*}=\alpha V+(1-\alpha)C$$

and payoffs for the developer and the end-user are proportional to their bargaining powers.

The higher the bargaining power, the more benefit one will gain from the GB transaction. The lower the bargaining power, the less benefit one will gain from the GB transaction. Between developer and end-user, the one who gets more bargaining power will gain the most benefits from GB investment or purchase.

As discussed above, the benefit of the GB product, in terms of money, is dependent on various factors such as energy saving amount in life cycle of the GB product, energy price, discount rate, as well as behavior and lifestyle of end-user. The higher the energy price, the higher the benefit of the GB, other things being equal. We further extend the model to consider the externality of GB from the perspective of society.

From the perspective of society, with externalities considered, the benefit of the GB product is usually undervalued. As for energy price, the developer and the end-user usually take the current price or the expected price of energy in their decision making processes for evaluating the benefit from the GB product. However, to solve the externality problems from exploring and consuming energy, the shadow price of energy, which incorporates lifetime damage cost associated with energy consumption, should be much higher from the perspective of society. In such situations, the benefit of GB should be higher, too. Suppose it is V_1, and $V_1 > V$, yielding the equilibrium price of GB from the perspective of society. Suppose it is P_1^* is given by

$$P_1^{*}=\alpha V_1+(1-\alpha)C>P^{*}=\alpha V+(1-\alpha)C$$

We can note that the market price of energy is mostly lower than the shadow price of energy, when externalities are considered and benefits of the GB are commonly undervalued in practice. Hence, it is necessary for government to play an effective role to correct the market signal to reflect the real energy and electricity price, through regulations, and administrative measures (Proofs of the Proposition can be found in Appendix).

By solving the Nash bargaining solution of the game model considering no TCs above, we concluded that the transaction of the GB is feasible and possible, as long as the benefit of the GB exceeds its cost. However, due to the inevitable TCs associated with searching, negotiating, and monitoring for both the developer and the end-user, the transaction of the GB in the real world may not happen, and the price of the GB mostly varies from the equilibrium price in the game model. We propose the following systemic game model to explore the impacts of TCs as a whole on the developer and the end-user regarding decisions on GB investment.

4.2. Game model between the developers and end-users with TCs

Suppose, associated with the transaction of the GB product, the TCs for the developer is TC_D; for the end-user, it is TC_C, which are common knowledge for both. In such a situation, the cost to develop the GB is higher, and the benefit of the GB is lower, compared with those in the scenario without TCs.

Proposition 2. *The unique equilibrium price of the GB in the game model between the developer and the end-user with TCs is given by*

$$P^{**}=\alpha V+(1-\alpha)C+(1-\alpha)TC_D-\alpha TC_C$$

The payoffs for the developer and the end-user are given by

$$Q_D^{*}=P^{**}-C-TC_D=\alpha(V-C-TC_C-TC_D)$$

$$Q_C^{*}=V-TC_C-P^{*}=(1-\alpha)(V-C-TC_C-TC_D)$$

which are less than those in the scenario without TCs and proportional to their bargaining powers.

As supposed previously, $TC_C, TC_D > 0$, compared with the payoffs in the game model without TCs, we have: $Q_D^{*} < Q_D$ and $Q_C^{*} < Q_C$.

Consider the precondition of the transaction: in the game model without TCs, the transaction would be viable as long as V > C. In the game model with TCs, however, the transaction would be viable only if $V > C + TC_D + TC_C$, demonstrating that it is more difficult for the developer and the end-user to reach an agreement if high TCs are involved. In addition, we compare the equilibrium price of the GB above with that in the game model without TCs, yielding that

$$P^{**}=P^{*},\ \text{if}\ \alpha=\frac{TC_D}{TC_C+TC_D}.$$

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$$P^{**} > P^{*}, \text{ if } \alpha < \frac{TC_D}{TC_C+TC_D}.$$

$$P^{**} < P^{*}, \text{ if } \alpha > \frac{TC_D}{TC_C+TC_D}.$$

Hence, the change of equilibrium price of GB is related to the relative bargaining power and TCs of the developer and the end-user with respect to GB. The higher the bargaining power for the end-user, the lower the price of the GB in the equilibrium, other things being equal (Proofs of the Proposition can be found in Appendix).

4.3. Game model with TCs from the aspect of uncertainties

The determinants of TCs, according to Oliver E. Williamson, are frequency, specificity, uncertainty, limited rationality, and opportunistic behavior. In reality, due to the constraints from limited rationality and opportunistic behavior, it is difficult to quantify each specific TCs in the GB market and imagine that the developers and the end-users effectively identify and execute the best or most rational strategy accordingly at every stage. Moreover, it is difficult to decide the frequency of transactions in the GB market, since it is a one-off deal for most end-users whilst a rather repeated one for most developers. In this regard, we focus only on the uncertainty features of TCs and further improve the game model to investigate and reveal the impacts of TCs in specific to uncertainty. Rather than focusing on the precise scale of TCs, the assumption of uncertainties makes the model more realistic and universal. Moreover, by analyzing the differences between the perceived and actual uncertainties, it sheds light on the TCs impacts from limited rationality and opportunistic behavior.

TCs, due to uncertainties (e.g., information asymmetry) are the fundamental barriers in the game between the developer and the end-user in the GB market. The uncertainties come either from the nature of the GB transaction, such as costs in acquiring information; the difficulty in evaluating the real benefit from improved energy efficiency performance; or other unexpected factors, such as the market situation, preferences, macroeconomic conditions, energy prices, etc. It is reasonable, therefore, to assume rational developers and end-users will make their decisions based on maximization of their expected utilities, taking uncertainties into account.

Following Bayesian game theory and John C. Harsanyi's framework, we extend the bargaining game model into one with incomplete information. According to the propositions and analysis above, we frame the model in which there is a monopoly developer facing a mass of heterogenous end-users. Assume that the developer may be one of two types: he may develop the genuine GB and sell it to the end-user or he may develop a false one: a conventional building. Suppose only the former situation: he will negotiate with the end-user over the price of the GB product, and the transaction of the GB will be through if they reach an agreement. The developer and the end-user are both economically rational and act strategically; the developer is to maximize his profit from developing the GB product, and the end-user is to maximize his utility from purchasing the GB product.

To formalize the ideas, suppose for the developer, the extra cost needed to develop the GB is C and for the end-user, the additional utility brought from purchasing the GB is V, and $V > C$. The developer and the end-user are negotiating over the price P for GB. For simplicity, suppose the cost to develop a conventional building and the utility from purchasing it are both 0. Similar to the previous analysis, we can model the negotiation process as a bargaining problem; suppose α and $1-\alpha$ represent the bargaining powers for the developer and the end-user respectively.

In the scenario with incomplete information, we assume that the type of developer belongs to the group starting with the two-point probability distribution (i.e., the probability is p if he develops the GB, and $1-p$ if he does not). In the situation when the developer chooses to develop the GB, for simplicity, suppose the extra cost C needed to develop the GB is common knowledge. The utility that the end-user gains from purchasing the GB is private information. In other words, the developer does not know the utility of each end-user ex ante and just knows the distribution. Without losing generality, we assume the utility V follows the continuous uniform distribution on [0, M], where M is the highest extra utility the end-user may gain from purchasing the GB product.

We now only focus on the situation when the developer chooses to develop the GB and negotiates with the end-user over the price of GB. If TCs are considered, suppose TC_D and TC_C denote TCs associated to reach an agreement for the developer and the end-user respectively. Note that in contrast to common cost C for developing GB, we suppose information regarding TCs is private information.[2] It is noteworthy that the assumptions above also reflect the fundamental characteristics of the GB market. Statistically speaking, the probability distribution of the developer can be interpreted as the proportion of credible developers that develop GB products in the market, while the probability distribution of the end-user can be regarded as the distribution of end-user demand with varied willingness to pay.

Consider the game process. In the situation when the developer chooses not to develop GB, extra utilities for the developer and the end-user are both 0. In the situation when the developer develops GB, if the price P of the GB exceeds the benefit V for the end-user, the end-user will choose not to negotiate and the transaction will not occur; then the payoff for the developer is $-C$ and the payoff for the end-user is 0. Only in the situation when the price P of the GB is smaller than the benefit V for the end-user will the developer and the end-user start to negotiate over the price. In addition, if it would reach an agreement, the payoff for the developer is $P - C - TC_D$, while for the end-user it is $V - P - TC_C$, with TCs taken into consideration. If the agreement fails, the payoff for the developer is $-C - TC_D$, and for the end-user it is $-TC_C$. The complete game tree is shown in Fig 1.

5. Modeling results and discussions

5.1. Equilibrium outcomes for the end-user

This is a typical Stackelberg competition[3]-leader-follower game between the developer and the end-user. The developer will decide whether or not to develop the GB first, while his decision is dependent on the beliefs about the moves by the end-user. Therefore, we adopt backward induction to solve the equilibriums in the game, by investigating the optimal decisions by the end-user first. The reason is that only when the end-users gets his optimal choice, the transaction will go through. With the optimal decision,

[2] As discussed previously, in the complete information scenario, TCs can be regarded the same as common costs for developing or purchasing GB, which is deemed as an indispensable for both the developer and the end-user. In the asymmetric information scenario, we divide the TCs into two parts: one is common knowledge and the other is not.

[3] The model is solved by backward induction. The leader considers what the best response of the follower is, i.e. how it will respond once it has observed the quality of the leader. The leader then picks a quantity that maximizes its payoff, anticipating the predicted response of the follower. The follower actually observes this and in equilibrium picks the expected quantity as a response. (http://en.wikipedia.org/wiki/Stackelberg_competition).

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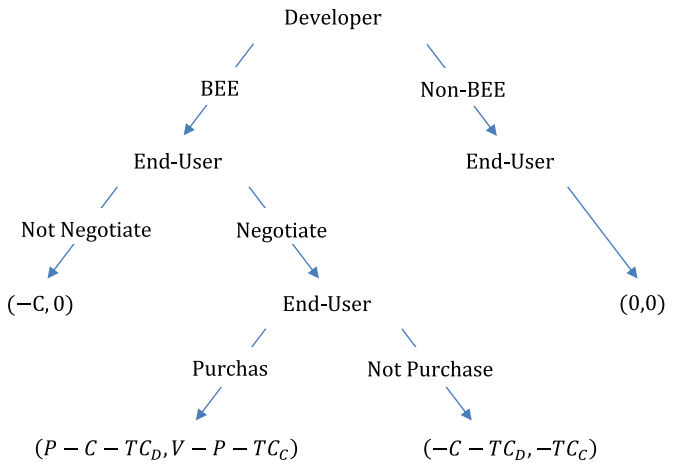

Fig. 1. Game Tree for the game between the developer and the end-user.

the developer will make his decision accordingly in order to complete the transaction.

Proposition 3. *The end-user will negotiate with the developer and purchase the GB if the benefit is* $V \geq C + \frac{TC_C}{1-\alpha}$ *and will not purchase the GB if* $V < C + \frac{TC_C}{1-\alpha}$. *The expected utility for the end-user is given by*

$$EQ_C = \begin{cases} p[(1-\alpha)(V-C) - TC_C], & \text{if } V \geq C + \dfrac{TC_C}{1-\alpha} \\ 0, & \text{if } V < C + \dfrac{TC_C}{1-\alpha} \end{cases}$$

Compared with the scenario without TCs, the expected utility is less, due to

$$EQ_C < Q_C = (1-\alpha)(V-C)$$

Obviously, when the developer chooses to develop the GB product, the end-user will not choose the strategy of "negotiate, not purchase," which is a strictly dominated strategy. Thus, the end-user will only choose between "not negotiate, not purchase" or "negotiate, purchase." If the expected payoff is positive, the end-user will choose to negotiate and purchase the GB product. If the expected payoff is negative, the end-user will choose not to negotiate and not purchase the GB product (Proofs of the Proposition can be found in Appendix).

Consider the precondition of the transaction: in the scenario without TCs, the transaction would be viable as long as $V > C$. Here, because $\frac{TC_C}{1-\alpha}$ is positive, demonstrating that it is more difficult for the developer and the end-user to reach an agreement in a scenario with TCs than the one without. Besides, the market demand is decreasing due to higher TCs, as well as lower bargaining power for the end-users. The expected utility EQ_C is in a monotone increasing function with respect to the probability p, (i.e. the higher probability for the developer to develop the GB product, the more expected utility is for the end-user.) (Proofs of the Proposition can be found in the Appendix).

5.2. Equilibrium outcomes for the developer

We consider the optimum decision for the developer similar to that of end-users accordingly. If the developer believes that the end-user will not purchase the GB product, then the best response for the developer is not to develop, with the payoff being 0. If the developer believes the end-user will negotiate and purchase the GB product, then the developer will develop the GB product and have three strategies: "not negotiate, not sell", "negotiate, sell," and "negotiate, not sell," with the payoffs being $-C$, $P - C - TC_D$, and $-C - TC_D$, respectively.

Similar to that of the end-users above, when the developer chooses to develop the GB product, he will not choose the strategies of "not negotiate, not sell" or "negotiate, not sell," which are both dominated strategies. Therefore, the developer will only choose between "not develop" or "negotiate, sell" after developing the GB product, while taking the former choice if the expected utility is negative, and the latter one if positive.

Proposition 4. *The developer will develop the GB and sell it to the end-user through negotiation if the TCs associated satisfy the following constraints*:

$$TC_C \leq (1-\alpha)(M-C)$$

$$TC_D \leq \frac{\alpha}{2}\left(M - C + \frac{TC_C}{1-\alpha}\right)$$

The developer will not develop the GB if

$$TC_C > (1-\alpha)(M-C) \text{ or } TC_D > \frac{\alpha}{2}\left(M - C + \frac{TC_C}{1-\alpha}\right)$$

The expected utility for the developer is given by

$$EQ_D = \begin{cases} \dfrac{\alpha}{2M}\left(M + \dfrac{TC_C}{1-\alpha} - C - \dfrac{2TC_D}{\alpha}\right)\left(M - C - \dfrac{TC_C}{1-\alpha}\right), \\ \text{if } TC_C \leq (1-\alpha)(M-C) \text{ and } TC_D \leq \dfrac{\alpha}{2}\left(M - C + \dfrac{TC_C}{1-\alpha}\right) \\ 0, \\ \text{if } TC_C > (1-\alpha)(M-C) \text{ or } TC_D > \dfrac{\alpha}{2}\left(M - C + \dfrac{TC_C}{1-\alpha}\right) \end{cases}$$

As proved (Proofs of the Proposition can be found in the Appendix), for the developers, the decisions over developing GB products are related to the distribution of utilities of the end-users, the development costs for GB, the TCs, and the bargaining powers. Furthermore, suppose the GB products are developed, we will investigate the impacts on the expected utilities for the developer from factors such as utilities of end-users, development cost, TCs, and bargaining powers.

Proposition 5. *If the developer chooses to develop GB products, the expected utility will increase with the improvement of utility for the end-user from purchasing the GB product.*

To conclude, if the developers believe it is profitable to develop GB products, the higher utilities the end-users will gain from GB products, the more profits the developers will expect from developing GB, other things being equal. In other words, since M also reflects the distribution of market demand for GB, the expected profits for the developers will be boosted if demand for GB products increases (Proofs of the Proposition can be found in the Appendix).

Proposition 6. *If the developer chooses to develop GB products, the expected utility will decrease with the increase of development cost of GB or TCs for the developer.*

Clearly, the expected profits from developing GB products will be lower if the developers face higher development costs and associated TCs (Proofs of the Proposition can be found in the Appendix).

Proposition 7. *If the developer chooses to develop GB products, the expected utility for the developer will increase with the increase of TCs for the end-user if the TCs for the end-user satisfy*

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$$TC_C < \frac{2(1-\alpha)}{\alpha} TC_D$$

The expected utility for the developer will decrease with the increase of TCs for the end-user if the TCs for the end-user satisfy

$$TC_C \geq \frac{2(1-\alpha)}{\alpha} TC_D$$

The reason is as follows: with the increase of TCs for the end-user, the equilibrium price of the GB through negotiation between the developer and the end-user will decrease accordingly. On the one hand, when TCs for the end-user are small, the possibility that the end-user will purchase the GB is relatively high; thus, the expected utility for the developer may increase, even with the increase of TCs for the end-user. On the other hand, when TCs for the end-user are big enough, not only is the possibility for the transaction of the GB decreasing, but also the equilibrium price is lower. Therefore, the expected utility for the developer may decrease with the increase of TCs for the end-user. (Proofs of the Proposition can be found in the Appendix).

Proposition 8. *If the developer chooses to develop GB products, the expected utility for the developer will increase with the increase of his bargaining power if the bargaining power for the developer satisfies*

$$0 < \alpha < 1 - \frac{\sqrt{TC_C(TC_C - 2TC_D)}}{M - C}$$

The expected utility for the developer will decrease with the increase of his bargaining power if the bargaining power for the developer satisfies

$$1 - \frac{\sqrt{TC_C(TC_C - 2TC_D)}}{M - C} < \alpha < 1$$

The reason is similar to that in Proposition 7. When the bargaining power for the developer is relatively low, the expected utility for the developer will increase with the strengthening of his bargaining power, since the equilibrium price of the GB will increase accordingly. However, when the bargaining power for the developer is relatively high, despite increasing equilibrium price, the probability for the transaction of the GB is lowering, leading to the decrease of expected utility for the developer (Proofs of the Proposition can be found in the Appendix).

To simplify, we only consider the TCs incurred in the negotiation process between the developer and the end-user. Suppose in the scenario with TCs, the developer will choose to negotiate with the end-user over the transaction of the GB product; its expected utility EQ_D is given as in Proposition 4. In the alternative scenario without TCs, there is neither a negotiating nor a bargaining process. Instead, suppose the developer puts a fixed price for the GB product; let P_1 denote the fixed price. The end-user will only purchase the GB if the fixed price is smaller than the utility; that is, $V \geq P_1$. In this scenario, the developer has to find the optimal price to maximize his expected utility. Let EQ_D^1 denote the new expected utility.

In the scenario without TCs, we have

$$EQ_D^1 = \int_{V \geq P_1}^{M} (P_1 - C) * \frac{1}{M} dV = \int_{P_1}^{M} (P_1 - C) * \frac{1}{M} dV$$
$$= (M - P_1)(P_1 - C) * \frac{1}{M}$$

To find the optimal fixed price of the GB product, we solve the following maximization problem, given by

$$\max_{P_1} EQ_D^1 = (M - P_1)(P_1 - C) * \frac{1}{M}$$

Set $\frac{\partial EQ_D^1}{\partial P_1} = 0$, yielding the optimal fixed price:

$$P_1 = \frac{M + C}{2}$$

And the expected utility for the developer is

$$EQ_D^1 = \frac{(M - C)^2}{4M}$$

Note here the outcome is just the extreme case of the general model outlined above, when TCs for the developer and the end-user during the negotiation and bargaining process are both 0, with the same bargaining power.

Proposition 9. *For the developer, the expected utility is bigger in the scenario with TCs than in the scenario without TCs if*

$$TC_D \leq \frac{\alpha}{2}\left(M - C + \frac{TC_C}{1-\alpha}\right) - \frac{(M-C)^2}{4\left(M - C - \frac{TC_C}{1-\alpha}\right)}$$

The expected utility is smaller in the scenario with TCs than that in the scenario without TCs, if

$$TC_D > \frac{\alpha}{2}\left(M - C + \frac{TC_C}{1-\alpha}\right) - \frac{(M-C)^2}{4\left(M - C - \frac{TC_C}{1-\alpha}\right)}$$

By solving the inequalities$EQ_D \geq EQ_D^1$ and $EQ_D < EQ_D^1$, we can deduce the outcomes above.

$TC_D \leq \frac{\alpha}{2}\left(M - C + \frac{TC_C}{1-\alpha}\right) - \frac{(M-C)^2}{4\left(M-C-\frac{TC_C}{1-\alpha}\right)}$, which means the developers actually enjoy the TCs and are better-off because of it. Also, it means that the developers would rather choose to negotiate and bargain with the end-users instead of setting a designated price. While in the scenario of $TC_D > \frac{\alpha}{2}\left(M - C + \frac{TC_C}{1-\alpha}\right) - \frac{(M-C)^2}{4\left(M-C-\frac{TC_C}{1-\alpha}\right)}$, the developers would prefer to set a designate price rather than negotiate with the end-users due to the higher TCs. Therefore, the developers could be able to choose a different price to determine a strategy to maximize their expected utility. Noteworthy, this gives additional insights about TCs. In some cases, the developer will choose strategies with higher TCs to maximize the expected profits. The reason is as follows: in the scenario without TCs, implying there are no negotiations, the developer charges the same price for the end-users whose utility is higher than the fixed price of the GB product. By contrast, in the scenario with TCs, the developer with higher bargaining power might be better-off due to price discrimination through negotiation, if the TCs associated are relatively low.

6. Discussion of the findings

In the above, the nine propositions regarding the game modeling between developers and end-users are proposed, including with/without considerations of TCs, and the specific aspect of TCs in terms of uncertainty. They all serve the different purpose, which explains and implies the TCs impacts to the decision-making of GB between the two stakeholders.

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6.1. Proposition 1

From the perspective of society, with externalities considered, the benefit of the GB product is usually undervalued. The market price of energy is mostly lower than the shadow price of energy when externalities are considered. Therefore, the benefits of the GB are undervalued in practice, and the equilibrium amounts of GB supply and demand are lower than the social, optimal level. Hence, it is necessary for government to play an effective role to correct the energy price to reflect to its true market value, and adjust to the market signal through policies such as incentives, regulations, awareness, and administrative measures in order to promote and develop the GB market.

The equilibrium price of the GB is dependent on its cost, benefit, as well as the relative bargaining power between the developer and the end-user. The equilibrium payoffs for the developer and the end-user are proportional to their bargaining powers. The higher the bargaining power, the more benefit one will gain from the GB transaction. For example, in Hong Kong, real estate developers are dominating the market, and therefore have more bargaining power over the end-users on what to offer to the market. Therefore, incentive given to the developers in such context may take better effect to leverage the GB market growth.

6.2. Proposition 2

TCs are proved as overriding barriers impeding the development of the GB market. The game model highlights the stakeholders' behaviors in the real world. The developers will stress or exaggerate the difficulties, risks, and uncertainties, in terms of TCs, in order to secure his bargaining power over price during the GB negotiation. The end-users will in turn emphasize the uncertainties about the GB performance caused by the TCs in terms of money, time, and risk, to ask for the lowest negotiating price. Reducing the TCs will facilitate the supply and demand of GB in market and get more GB transactions through. The condition for the transaction of the GB with TCs is stricter, compared with that without TCs. That is to say, the higher the associated TCs are, the more difficult it is for the developer and/or the end-user to reach an agreement over the transaction of the GB product. Incentives designed to reduce the TCs incurred to the relevant parties will ensure the considerable GB transactions.

6.3. Proposition 3

The end-users' decisions regarding GB are related to the overall utility, the development cost, the associated TCs, and end-user's bargaining power. If the TCs faced by the end-user are relatively high, reducing the TCs of the end-users can increase the expected utilities for the developer. However, if the TCs for the end-user are relatively low, reducing the TCs may decrease the expected utilities for the developer.

From a broad view, a real estate sector with a high proportion of developers investing on GB will reduce the overall TCs associated and increase the payoffs for the end-users. Governments should implement incentives to raise the probability or proportion of the developers who choose to develop GB products, which in turn increases the end-users' expected utility from the GB product, and benefit the long-term development of the GB market. On the contrary, more developers with less credibility in terms of faking GB will result in higher TCs for the end-users and lower expected payoffs. Therefore, publicity information on the green buildings available, accessible and credible is important for the end-users, as well as their guaranteed performance in operation and maintenance.

6.4. Proposition 4–9

Developers' decisions on GB are related to the distribution of end-users' utility, the development costs for GB, the TCs, and the bargaining powers for the developer and the end-user. Reducing the TCs can increase the expected utilities for the developers, expanding market supply of GB product. Besides, strengthening the bargaining power of the developer can increase the expected utility of developing GB. However, if the bargaining power for the developer is already high enough, further enhancing the bargaining power of the developer might decrease his utility due to the retreat from the end-users.

The key point is that in view of incomplete information, uncertainties, unfair competition, free riders, etc. in the GB market, which cause the TCs, a rational developer would not be willing to develop GB. In other words, TCs associated with information searching, risk, and uncertainties in an information incomplete market would undermine the advantages of GB. In the long run, information diffusion, technology advancement, increasing awareness, and institution improvement, will boost the demand for GB. These could be improved by market stakeholders' self-regulating and co-operation and information sharing through co-ordination of professional organizations or NGOs.

7. Recommendations

This study contributes to regenerative development that seeks further improvement in the process so that the overall output is greater than or equaling to the input. It has explored the full deployment the known technical contribution of GB to urban sustainability by unearthing and reducing the TCs involve in the GB investment transactions. From the above findings, we develop the following recommendations which will help to energize the GB markets and smoothen the GB investment with lower TCS incurred pointing to overall societal gain:

- The government should design more favorable green incentives to the parties who hold more bargaining powers on GB transactions, e.g., the developers in the current context of Hong Kong, in order to leverage more supply of green buildings. (Refer to findings proposition 1)
- There should be incentive designed to the specific stakeholders in order to reduce their TCs incurred. Reducing the TCs should be at the top of the government's priority list to promote the GB market to an optimal level. (Refer to findings proposition 2)
- Governments should stimulate the market demand for GB by increasing the expected utility for the developers; i.e. increasing the benefits of GB, reducing the development costs and TCs associated with incentive measures, energy or carbon taxes, energy auditing or labeling program for the new and existing GB, etc. (Refer to findings proposition 3)
- Given the asymmetric information in the real world, governments can play a proactive role in areas such as R&D in GB technologies, awareness, dissemination of innovative design and pilot projects, etc. Moreover, the government should provide support to facilitate collaboration among building users and increase their bargaining power. A competitive and credible real estate market is the healthy foundation for GB market to grow (Refer to findings proposition 4–9).

8. Conclusions

The game modeling of TCs in this study reinforces the understanding of the breadth and depth of the hidden concerns in terms

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of TCs that affect the GB participatory relationship and therefore shapes the results of GB transactions. The study concludes that TCs are the key factors impeding GB market penetration. The modeling has highlighted the impacts of TCs to the GB decisions. The study results also emphasize the importance of institutions in the GB market to secure a level playing field. The identified stakeholders' concerns provide reference for government-making policy to encourage the developers and end-users to invest in GB with reduced TCs in a new market system that bring extra benefit to everyone. The findings also provide theoretical insights about transactions in the GB market and how TCs play its role in inhibiting the GB market.

The game modeling approach explains the underlying human systems in an interactive decision-making process. By expressing the relationships of the developer and end-user in their decision-making on GB in the form of TCs' existence, it is possible to engage more quickly the layperson in an understanding of the complex relationships with direct and concrete results from the calculation. It functions as a metaphor to communicate the ideas quickly and powerfully to the real world in practice (Reed, 2007). The way of working can deliver not only more holistic and effective understanding of the process but also a higher level of satisfaction between the developer and end-user in terms of upcoming incentives designed to adjust their needs and concerns during the decision-making process of GB. These stakeholders of GB are, therefore, increasingly able to play a meaningful role as integral part of the community to engage in regenerative development of GB. By modeling and identifying positive roles played by different stakeholders in the complex game situations on GB, it brings net positive outcomes to society. Its success in implementation will help the paradigm shift towards regenerative development for the urban built environment that supports a genuinely sustainable society.

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Appendix 1

Proofs of Propositions.

Proposition 1.

Proof: To determine the Nash bargaining solution, we take the derivative of Q with respect toP, and set it to zero for maximization:

$$\frac{\partial Q}{\partial P} = \alpha(P - C)^{\alpha-1}(V - P)^{1-\alpha} - (1-\alpha)(P - C)^{\alpha}(V - P)^{-\alpha} = 0$$

$$\alpha(P - C)^{\alpha-1}(V - P)^{1-\alpha} = (1-\alpha)(P - C)^{\alpha}(V - P)^{-\alpha}$$

$$\alpha(P - C)^{-1}(V - P) = 1 - \alpha$$

Yielding the equilibrium:

$$P^* = \alpha V + (1-\alpha)C$$

And the payoff for the developer:

$$Q_D = P^* - C = \alpha(V\text{-}C)$$

The payoff for the end-user:

$$Q_C = V - P^* = (1-\alpha)(V - C)$$

Hence, we have:

$$\frac{Q_D}{Q_C} = \frac{\alpha}{1-\alpha}$$

Proposition 2.

Proof: In the game model with TCs, solving the equilibrium price of the GB can be expressed as solving the following optimization problem, given by:

$$\max_P Q = (P - C - TC_D)^{\alpha}(V - TC_C - P)^{1-\alpha}$$

Take the derivative of Q with respect to P, and set it to zero for maximization:

$$\frac{\partial Q}{\partial P} = 0$$

Yielding the equilibrium price:

$$P^{**} = \alpha(V - TC_C) + (1-\alpha)(C + TC_D)$$
$$= \alpha V + (1-\alpha)C + (1-\alpha)TC_D - \alpha TC_C$$

And the payoff for the developer:

$$Q_D^* = P^{**} - C - TC_D = \alpha(V - C - TC_C - TC_D)$$

The payoff for the end-user:

$$Q_C^* = V - TC_C - P^* = (1-\alpha)(V - C - TC_C - TC_D)$$

And clearly:

$$\frac{Q_D^*}{Q_C^*} = \frac{\alpha}{1-\alpha}$$

Proposition 3.

Proof: For the end-user, we consider the optimum decision by investigating his reactions in different situations separately.

If the end-user believes that the developer will not develop the GB product, then the best response for the end-user is not to negotiate nor purchase it, with the payoff being 0. If the end-user believes the developer will develop the GB product, then he has three strategies: “not negotiate, not purchase”, “negotiate, not purchase”, “negotiate, purchase”, with the payoffs being 0, $-TC_C$, $V - P - TC_C$ respectively. In more details, to solve the equilibrium price of the GB product, we solve the following optimization problem, given by:

$$\max_P Q = (P - C)^{\alpha}(V - P)^{1-\alpha}$$

Set the first derivative of Q with respect to P to zero for maximization:

$$\frac{\partial Q}{\partial P} = 0$$

Yielding the equilibrium price:

$$P^* = \alpha V + (1-\alpha)C$$

And the expected payoff for the end-user is given by:

$$EQ_C = p * (V - P^* - TC_C) + (1-p)*0 = p[(1-\alpha)(V - C) - TC_C]$$

Solving $EQ_C \geq 0$, we have:

$$V \geq C + \frac{TC_C}{1-\alpha}$$

Proposition 4.

Proof: According to the optimal decisions for the end-user above, as well as the hypothesis of continuous uniform distribution on [0, M] for utilities of the end-users, for the developer, the end-user will choose to negotiate and purchase the GB if and only if the utilityV satisfies:

$$C + \frac{TC_C}{1-\alpha} \leq V \leq M$$

Then the expected payoff for the developer is given by:

$$EQ_D = \int_{C+\frac{TC_C}{1-\alpha}}^{M} (P^* - C - TC_D) * \frac{1}{M} dV$$

To solve the equilibrium price of the GB product, refer to the proof of Proposition 10, which has:

$$P^* = \alpha V + (1-\alpha)C$$

Consequently, the expected utility for the developer can be transformed as:

$$EQ_D = \int_{C+\frac{TC_C}{1-\alpha}}^{M} (P^* - C - TC_D) * \frac{1}{M} dV$$

$$= \int_{C+\frac{TC_C}{1-\alpha}}^{M} [\alpha(V-C) - TC_D] * \frac{1}{M} dV$$

Solving the integral problem, yielding the expected utility:

$$EQ_D = \frac{\alpha}{2M}\left(M + \frac{TC_C}{1-\alpha} - C - \frac{2TC_D}{\alpha}\right)\left(M - C - \frac{TC_C}{1-\alpha}\right)$$

Since $\frac{\alpha}{2M} \geq 0$, and the inequality$M - C - \frac{TC_C}{1-\alpha} \geq 0$ holds due to $C + \frac{TC_C}{1-\alpha} \leq V \leq M$, thus to solve $EQ_D \geq 0$, we have:

$$TC_D \leq \frac{\alpha}{2}\left(M - C + \frac{TC_C}{1-\alpha}\right)$$

Proposition 5.

Proof: Take the derivative of EQ_D with respect to M, we have:

$$\frac{\partial EQ_D}{\partial M} = \frac{\alpha}{2} + \frac{\alpha}{2M^2}\left(\frac{TC_C}{1-\alpha} - C - \frac{2TC_D}{\alpha}\right)\left(C + \frac{TC_C}{1-\alpha}\right)$$

When the developer chooses to develop GB products, implying that:

$$TC_D \leq \frac{\alpha}{2}\left(M - C + \frac{TC_C}{1-\alpha}\right)$$

the end-user chooses to negotiate and purchase the GB if and only if the utility V satisfies:

$$C + \frac{TC_C}{1-\alpha} \leq V \leq M$$

Then,

$$M - C - \frac{TC_C}{1-\alpha} \geq 0$$

Then we have:

$$\frac{\partial EQ_D}{\partial M} = \frac{\alpha}{2} + \frac{\alpha}{2M^2}\left(\frac{TC_C}{1-\alpha} - C - \frac{2TC_D}{\alpha}\right)\left(C + \frac{TC_C}{1-\alpha}\right) \geq \frac{\alpha}{2} - \frac{\alpha}{2M}\left(C + \frac{TC_C}{1-\alpha}\right) = \frac{\alpha}{2M}\left(M - C - \frac{TC_C}{1-\alpha}\right) \geq 0$$

Proposition 6.

Proof: Take the derivatives of EQ_D with respect to C and TC_D respectively, we have:

$$\frac{\partial EQ_D}{\partial C} < 0$$

$$\frac{\partial EQ_D}{\partial TC_D} < 0$$

Proposition 7.

Proof: Take the derivatives of EQ_D with respect to TC_C, yielding:

$$\frac{\partial EQ_D}{\partial TC_C} = -\frac{\alpha TC_C}{M(1-\alpha)^2} + \frac{2TC_D}{M(1-\alpha)}$$

Then we have:

$$\frac{\partial EQ_D}{\partial TC_C} > 0, \text{ if } 0 < TC_C < \frac{2(1-\alpha)}{\alpha} TC_D.$$

$$\frac{\partial EQ_D}{\partial TC_C} \leq 0, \text{ if } TC_C \geq \frac{2(1-\alpha)}{\alpha} TC_D.$$

Hence, for the developer, there is a threshold of TCs for the end-user, set $\frac{2(1-\alpha)}{\alpha} TC_D = \theta$, if the TCs for the end-user is smaller than θ, the expected utility for the developer will increase with the increase of TCs for the end-user. If the TCs for the end-user are larger than θ, the expected utility for the developer will decrease with the increase of TCs for the end-user.

Proposition 8.

Proof: Take the derivatives of EQ_D with respect to α, yielding:

$$\frac{\partial EQ_D}{\partial \alpha} = \frac{(M-C)^2}{2M} - \frac{TC_C}{M(1-\alpha)^2}\left(\frac{TC_C}{2} - TC_D\right)$$

Since $0 < \alpha < 1$, then we have:

$$\frac{\partial EQ_D}{\partial \alpha} > 0, \text{ if } 0 < \alpha < 1 - \frac{\sqrt{TC_C(TC_C - 2TC_D)}}{M - C}.$$

$$\frac{\partial EQ_D}{\partial \alpha} < 0, \text{ if } 1 - \frac{\sqrt{TC_C(TC_C - 2TC_D)}}{M - C} < \alpha < 1.$$

Hence, there is threshold of bargaining power for the developer, other things being equal. Set$1 - \frac{\sqrt{TC_C(TC_C - 2TC_D)}}{M - C} = \varphi$, the expected utility for the developer will increase with the strengthening of his bargaining power α, if $0 < \alpha < \varphi$. The expected utility for the developer will decrease with the strengthening of his bargaining power α, if $\varphi < \alpha < 1$.

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