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Achieving Synergy of Complementary Projects through Social Coordination

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Abstract: Coordination in the implementation of complementary demand-driven infrastructure projects is projected to increase the efficiency and benefit of the undertaking. The task of the social coordinator, assumed to be the government in this paper, is to ensure that such coordination take place to increase joint benefit. On the other hand, from the optimal timing perspective, project proponents have four possible choices depending on the implementation schedule of the complementary project: *Implement now*, implement subsequent to complementary project (*Subsequent Implementer*), implement prior to complementary project (*Prior Implementer*), or *Synchronize Implementation.* The reaction functions of Project A in maximizing its net present value, given the timing of Project B, are simulated. Possible equilibrium conditions are derived using the concept of Nash Equilibrium for non-cooperative games. Framework for the viability of the possible strategies for coordination is evaluated using the concept of side payment.

Key Words: *optimal timing, synergy, social coordinator, side payment*

1. INTRODUCTION

Coordination is defined as the 'harmonious combination or interaction' of events or situations. When undertaken for projects, it is supposed to increase the efficiency and benefit of the undertaking. Yet despite the known complementary effect of urban development and infrastructure development projects or complementary transportation projects, instances of non-coordination of such projects abound due to a variety of causes. One source is the independent planning of various government agencies. This usually occurs when the responsibility of implementing various kinds of projects (i.e., transport, housing, urban development) is given to different government divisions or sections. Another source is the lack of effective policy instrument to synchronize such projects, especially when implemented by the private sectors.

This paper seeks to investigate the impact on optimal timing of complementary projects using concept of non-cooperative games. Due to the interactive nature of complementary projects, the choice of optimal timing for each project is affected by the optimal timing of the other project. Possible equilibrium scenarios are established using the reaction function as expressed in the choice of optimal timing of each project.

2. LITERATURE REVIEW

Researches on optimal investment timing decision in a multiple-project scenario shows that the interaction is often conceptualized as a game. Gans and Williams (1998) examined the 'effect of access regulation on incentives to invest in infrastructure that is subject to access

claim' under a system of 'regulation by negotiation'. In their model, a Provider (considered as the first investor) will undertake investment and an Access Seeker will want to access the infrastructure. It is assumed that the Access Seeker can negotiate with the Provider for access price. The bargaining process is conceptualized as an extensive form game and assumes that nature chooses the offerer (Provider) in each period. Moreover, the offerer makes a take-it-or-leave-it offer to the offeree (Access Seeker) who either accepts the offer or rejects it. However, in the event that the Provider and the Access Seeker cannot reach an agreement, a regulator may be called upon to arbitrate. It is further assumed that the regulator will always choose 'an access regime that maximizes social welfare'. The paper defines stand-alone timing as the 'timing the firm undertakes if it were the only firm to derive use from a facility' to maximize its pay-off. On the other hand, socially optimal investment timing is that which maximizes the sum of each firm's use values. The paper demonstrates that 'an appropriately specified access pricing rule can induce private firms to choose to invest in infrastructure at a socially optimal time'. Moreover, it concludes that using an optimal regulatory regime is superior to an unregulated environment in guiding optimal investment timing since it tends to compensate providers for a proportion of infrastructure value.

Chung and Tsou (1997) analyzed the optimal timing of investment in new manufacturing technologies (NMT) under duopolistic competition using a dynamic and non-cooperative game-theoretic model. The pay-off function of each firm is expressed in terms of the Net Present Value over time, contingent on the investment timing of the other firm. It identifies three initial options for any firm at the beginning of the timing game: immediate investments, investments after some delay, and forever prolongation. The paper concludes that when the firms are non-identical with respect to production cost, both firms will wait for some delay to invest in NMT since 'growing demand puts the firms in a more competitive environment where immediate investments and forever prolongation are dropped out'.

Levinson (2002) applied the theory of game in inter-temporal financing of infrastructure. For an equitable sharing of the burden of the cost of an infrastructure in a community between the old residents and a new development, financing schemes such as *Pay as you go*, *bond financing*, and *impact fees* are compared. The game is conceptualized as a one-time game where the objective of the players (community, developer) will be to minimize their own costs given the implementation of an infrastructure.

3. SOCIAL OPTIMAL TIMING: PURE TIMING PROBLEM

In this section, the Social Net Present Value of an independent project as well as its optimal timing will be defined. This is known as a pure timing problem (Marglin, 1963). The Social Net Present Value of a project *V(T)* may be expressed as:

$$V(T) = -I\exp(-\rho T) + \int_T^{\infty} \{b(t) - c(t)\}\exp(-\rho t)dt \tag{1}$$

where *V(T)* – net present value of the project, *I*-Investment cost, *b(t)* – annual benefit, *c(t)* – annual running costs, ρ-social discount rate, *T*-Timing of opening of service. However, the annual growth of net benefit, incurred only after the project has been implemented, may be expressed as:

$$b(t) - c(t) = (\bar{b} - \bar{c})\exp(\omega t) \tag{2}$$

where $(\bar{b} - \bar{c})$ is the initial value of the annual net benefit at t=0. Thus, equation *(1)* may be re-written as:

$$V(T) = -I\exp(-\rho T) + (\bar{b} - \bar{c})\int_T^{\infty} \exp\{(\omega - \rho)t\}dt \tag{3}$$

The Social Net Present Value is optimized at Optimal Timing T^*. In symbol, we have:

$$T^* = \arg\max_T V(T) \tag{4}$$

4. CONDITIONAL OPTIMAL TIMING: TWO-COMPLEMENTARY PROJECT

In this section the definition of Social Net Present Value in the previous section will be extended to a two-complementary project scenario. When a complementary project is implemented (represented as Project B), the Social Net Present Value of Project A is a function of optimal timing of Projects A and B and may be written as:

$$V_A(T_A, T_B) = -I_A\exp(-\rho T_A) + \int_{T_A}^{\infty} \Phi_A(t, T_B)\exp(-\rho t)dt \tag{5}$$

In equation *(5)*, $\Phi_A(t, T_B) = b(t, T_B) - c(t, T_B)$ and represents the net benefit term of Project A. It must be noted that in the formulation for the interactive condition, the net benefit term is a function of its own optimal timing as well as the timing of implementation of Project B. Taking the partial derivative of $V_A(T_A, T_B)$ with respect to T_A yields the marginal cost for delaying the opening of service, T_A:

$$\frac{\partial V_A(T_A, T_B)}{\partial T_A} = \rho I_A\exp(-\rho T_A) - \Phi_A(T_A, T_B)\exp(-\rho T_A) \tag{6a}$$

$$= \left[\rho I_A - \Phi_A(T_A, T_B)\right]\exp((-\rho T_A) \tag{6b}$$

Thus, the objective would be to determine the optimal timing T_A^* such that the condition for Global Maximum, including non-differentiable case, would be:

$$V_A(T_A^* - h, T_B) \le V_A(T_A^*, T_B) \text{ and } V_A(T_A^* + h, T_B) \le V_A(T_A^*, T_B) \tag{7a}$$

Likewise, the conditions for Local Maximum, if differentiable, will be:

$$\frac{\partial V_A(T_A^* - h, T_B)}{\partial T_A} > 0 \text{ and } \frac{\partial V_A(T_A^* + h, T_B)}{\partial T_A} < 0 \tag{7b}$$

or such that

$$\rho I_A - \Phi_A(T_A^* - h, T_B) > 0 \tag{7c}$$

and

$$\rho I_A - \Phi_A(T_A^* + h, T_B) < 0 \tag{7d}$$

where h is the displacement in time from the optimal timing T_A^*.

Equations *(7b)-(7d)* indicate that at any time *h* before T_A^*, the marginal change in opportunity cost is greater than the marginal net benefit of implementing the project, thus there is merit to delaying the opening of service. On the other hand, at any time h after T_A^*, the marginal net benefit of implementing the project is greater than the marginal increase in opportunity cost of capital investment, implying that it is no longer beneficial to delay the opening of service.

The expression for net benefit of Project A, $\Phi_A(t, T_B)$, conditional upon T_B, may be

decomposed into:

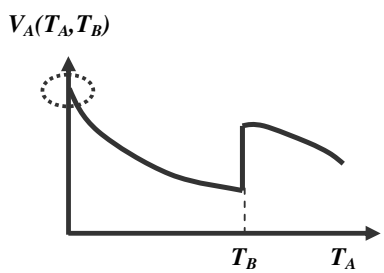
$$\Phi_A(t,T_B) = \begin{cases} \overline{\Phi}_A \exp(\omega_A t) \text{ for } t < T_B \\ \overline{\Phi}_A \exp(\omega_A^{\Delta} t) \text{ for } t \geq T_B \end{cases} \tag{8}$$

where the complementary effect of the projects is expressed in an enhanced growth rate of net benefit for Project A, ω_A^{Δ}. Likewise, using the appropriate expression from Equation *(8)*, equation *(6b)* may be transformed to:

$$\rho I_A - \Phi_A(T_A,T_B) = \begin{cases} \rho I_A - \overline{\Phi}_A \exp(\omega_A T_A) \text{ for } T_A < T_B \\ \rho I_A - \overline{\Phi}_A \exp(\omega_A^{\Delta} T_A) \text{ for } T_A > T_B \end{cases} \tag{9}$$

When $T_A<T_B$, Project A is called the *Prior Implementer* and when $T_A>T_B$, Project A is called the *Subsequent Implementer*.

There are four potential local optimal timing, T_A^*, as shown in figures 1 to 4.



Fig,1 Implement now

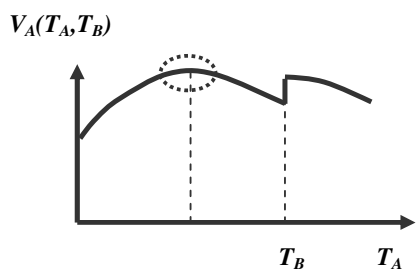


Fig. 2. Prior implementation

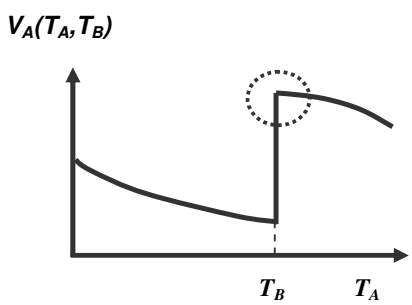


Fig. 3. Synchronized implementation

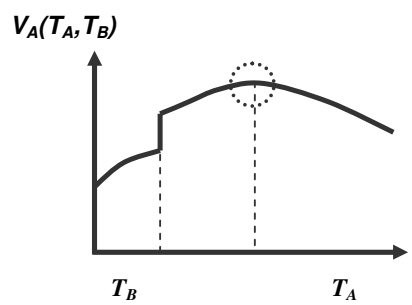


Fig. 4. Subsequent implementation

With h>0, the local maximum points shown may be described as follows, subject to the conditions stated in equations *(7c)* and *(7d)*:

For *implement now*:

$$\text{If } \rho I_A - \overline{\Phi}_A \exp\{\omega_A(0+h)\} < 0, \text{ then } T_A^* = 0 \tag{10}$$

For *prior implementation* of Project A to Project B:

$$\text{If } \rho I_A - \overline{\Phi}_A \exp\left[\omega_A \left\{\left(\frac{1}{\omega_A}\right)\ln\left(\frac{\rho I_A}{\overline{\Phi}_A}\right)\right\} - h\right] > 0 \text{ and } \rho I_A - \overline{\Phi}_A \exp\left[\omega_A \left\{\left(\frac{1}{\omega_A}\right)\ln\left(\frac{\rho I_A}{\overline{\Phi}_A}\right)\right\} + h\right] < 0,$$
$$\text{then } T_A^* = \left(\frac{1}{\omega_A}\right)\ln\left(\frac{\rho I_A}{\overline{\Phi}_A}\right) \tag{11}$$

In this case, its annual growth rate of net benefit remains at ω_A.

For *synchronized* opening of both projects:

$$\text{If } V_A(T_B - h, T_B) \le V_A(T_B, T_B) \text{ and } V_A(T_B + h, T_B) \le V_A(T_B, T_B),$$
$$\text{then } T_A^* = T_B \tag{12}$$

When Project A is opened after project B (*subsequent implementation*):

$$\text{If } \rho I_A - \overline{\Phi}_A \exp\left[\omega_A^\Delta \left\{\left(\frac{1}{\omega_A}\right)\ln\left(\frac{\rho I_A}{\overline{\Phi}_A}\right)\right\} - h\right] > 0 \text{ and } \rho I_A - \overline{\Phi}_A \exp\left[\omega_A^\Delta \left\{\left(\frac{1}{\omega_A}\right)\ln\left(\frac{\rho I_A}{\overline{\Phi}_A}\right)\right\} + h\right] < 0,$$
$$\text{then } T_A^* = \left(\frac{1}{\omega_A^\Delta}\right)\ln\left(\frac{\rho I_A}{\overline{\Phi}_A}\right) \tag{13}$$

All the equations derived are also applicable to Project B, with the corresponding change in project characteristics as denoted by the subscript.

5. REACTION FUNCTIONS

The objective of the proponents of Project A is to choose the optimal timing T_A^* that will maximize its Net Present Value, in reaction to the opening of service of Project B. In symbol this reaction function may be defined as:

$$T_A^*(T_B) = \arg\max_{T_A} V_A(T_A, T_B) \tag{14a}$$

Likewise, the reaction function of Project B may be described as:

$$T_B^*(T_A) = \arg\max_{T_B} V_B(T_A, T_B) \tag{14b}$$

Corresponding to the four potential local maximum points, using equation (5), Net Present Value may be defined as follows:

For Implement Now Scenario when $T_A^* = 0$,

$$V_A(0, T_B) = -I_A + \frac{\overline{\Phi}_A}{(\rho - \omega_A)} + \overline{\Phi}_A \left\{\frac{\exp(\omega_A^\Delta - \rho)T_B}{(\rho - \omega_A^\Delta)} - \frac{\exp(\omega_A - \rho)T_B}{(\rho - \omega_A)}\right\} \tag{15}$$

For *Synchronized Implementation* ($T_A^* = T_B$),

$$V_A(T_B, T_B) = -I_A \exp(-\rho T_B) + \frac{\overline{\Phi}_A}{(\rho - \omega_A^\Delta)} \exp\left(\omega_A^\Delta - \rho\right) T_B \tag{16}$$

For *Prior Implementation* ($T_A^* = \frac{1}{\omega_A}\ln\frac{\rho I_A}{\overline{\Phi}_A}$),

$$V_A\left(\tfrac{1}{\omega_A}\ln\tfrac{\rho I_A}{\Phi_A}, T_B\right) = I_A\left\{\frac{\overline{\Phi}_A}{\rho I_A}\right\}^{\frac{\rho}{\omega_A}}\left(\frac{\omega_A}{\rho-\omega_A}\right) + \overline{\Phi}_A\left[\frac{\exp\{(\omega_A^\Delta-\rho)T_B\}}{(\rho-\omega_A^\Delta)} - \frac{\exp\{(\omega_A-\rho)T_B\}}{(\rho-\omega_A)}\right] \tag{17}$$

For *subsequent Implementation* ($T_A^* = \frac{1}{\omega_A^\Delta}\ln\frac{\rho I_A}{\overline{\Phi}_A}$),

$$V_A\left(\tfrac{1}{\omega_A^\Delta}\ln\tfrac{\rho I_A}{\Phi_A}, T_B\right) = I_A\left(\frac{\overline{\Phi}_A}{\rho I_A}\right)^{\frac{\rho}{\omega_A^\Delta}}\left(\frac{\omega_A^\Delta}{\rho-\omega_A^\Delta}\right) \tag{18}$$

Therefore, at any given T_B, Project A will choose its optimal timing T_A^* that will yield the maximum Social Net Present Value:

$$T_A^* = \underset{T_A}{\arg\max}\left\{V_A(0,T_B), V_A(T_B,T_B), V_A\left(\frac{1}{\omega_A}\ln\frac{\rho I_A}{\overline{\Phi}_A}, T_B\right), V_A\left(\frac{1}{\omega_A^\Delta}\ln\frac{\rho I_A}{\overline{\Phi}_A}, T_B\right)\right\} \tag{19}$$

The equilibrium solution for this interactive optimal timing choice will be:

$$T_A^* = T_A^*(T_B^*) \text{ and } T_B^* = T_B^*(T_A^*) \tag{20}$$

where the solution is located on the reaction curves of both projects. However, for any game, the determination of the equilibrium consists in first identifying the reaction curve of each player. In this paper, when determining the reaction curves for the complementary projects, a simple fact was observed: if a 45-deg. line is drawn through the origin of the graph of the reaction curves, the only valid reactions above this line would be for Project A to *implement now*, *implement prior to*, or *synchronize*, with Project B. In the same space, the valid reactions for Project B, expressed in its choice of optimal timing, would be to *implement now*, *implement subsequently*, or to *synchronize* with Project A. For the space below the 45 deg. line, Project A may choose to *implement now*, *implement subsequent to*, or *synchronize* with Project B. Choice set of Project B includes *implement now*, *implement prior to* Project A, or *synchronize* its opening of service with Project A. There are at least four equilibrium scenarios that may be derived for the optimal timing of complementary projects, as illustrated in Figures 5-8. Figure 5 shows an equilibrium point where Project A is implemented subsequent to Project B. Thus, the equilibrium point is located below the 45-deg. line. Figure 6 illustrates the opposite scenario, where Project A is implemented prior to Project B. In figure 7, the only choice of optimal timing for both projects is to implement immediately. Figure 8 shows the case when there are multiple equilibrium points located on the 45-deg. line.

6. IMPLICATIONS TO SOCIAL COORDINATORS

In the previous section, several scenarios of equilibrium for non-coordinated conditions were shown. However, as has been mentioned at the beginning of this paper, coordination of the optimal timing of the opening of service of complementary projects may increase social surplus. Thus, using the behavior under non-coordinated case, various strategies may be adopted by the entity responsible for overseeing the coordination, herein referred to as the

social coordinator. In the following discussion, Project A will be used as reference in the labeling of the equilibrium point.

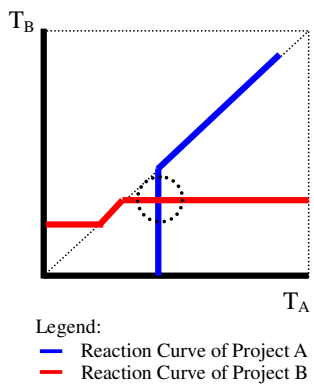


Fig. 5. Equilibrium when Project A is Subsequent Implementer

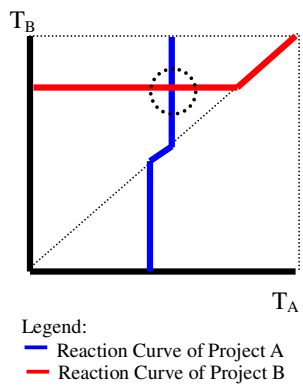


Fig. 6. Equilibrium when Project A is Prior Implementer

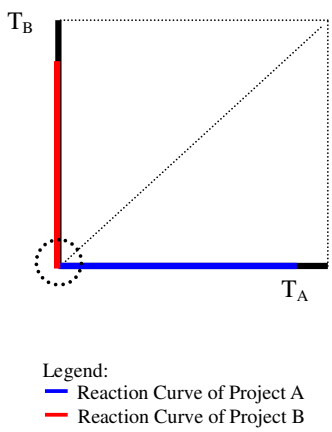


Fig. 7. Equilibrium point is at T=0

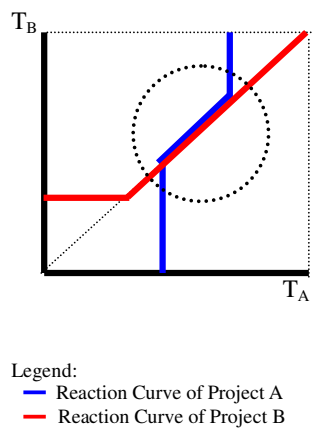


Fig. 8. Multiple synchronized equilibrium points

Figures 5 and 6 show equilibrium points for *Subsequent Implementer-Prior Implementer* and *Prior Implementer- Subsequent Implementer*, respectively. If upon the determination of the increase in social surplus, it is more beneficial to implement the projects earlier than the equilibrium timing, the task of the social coordinator is to offer incentives to the more crucial project. If we consider Project A to be the transportation infrastructure project, in the case where it naturally assumes the *Subsequent Implementer* role (i.e., it will be implemented subsequent to Project B, the Urban Development Project), the options for the social coordinator would be to either subsidize a portion of its Investment cost ***I*** or subsidize part of the annual running cost ***c***. Both strategies will, in effect, hasten the optimal timing of opening of service of Project A[3]. On the other hand, if a later opening of service is more prudent as far as increase of social surplus is considered, the social coordinator may levy taxes on the *Prior Implementer* to delay its optimal timing for opening of service.

For the case where there exist multiple synchronized equilibrium points, if deemed beneficial to encourage both projects to open at the earliest possible synchronized time, the social coordinator may offer a provisional incentive, such as subsidy for investment cost to the more crucial project or to both projects, as the case may be. It is provisional in the sense that it will only be granted if the projects agree to open at the optimal timing from the social net benefit perspective. To delay opening of service, investment cost I may be increased through policy instruments such as taxes. Table 1 shows the list of some strategies that are available to social coordinator to affect optimal timing of projects.

Although this is not an exhaustive list, it can give an indication of the capability of the model presented in this paper to assess government policies for project evaluation and coordination. On a final note, however, it must be stressed that in the granting of incentives, the resulting social benefit should be much greater than the incentives offered.

Table 1. Some strategies for timing coordination

Objective of Social Coordinator	***Parameters Change***	***Typical Forms of Policy Instruments***
Encourage earlier opening of service	Decrease I	Land acquisition incentive;
		Right of way acquisition incentive
	Decrease annual running cost c	Subsidize maintenance cost for infrastructure
		Tax Holiday
	Increase annual benefit b	Minimum ridership guarantee
		Right-to-develop depot into commercial establishments
Encourage later opening of service	Increase I	Asset taxes
	Increase annual running cost c	Income tax/sales tax
	Decrease annual benefit b	Regulated fare/selling price

7. SIDE PAYMENT CONCEPT IN COORDINATION

As previously mentioned, the role of the designated social coordinator is to always seek to improve joint social benefit. Thus if it perceives a possible improvement in the joint social benefit by revising the optimal timing of both projects, that is:

$$\Omega\left(T_A^*, T_B^*\right) < \Omega\left(T_A^* \pm h_A, T_B^* \pm h_B\right) \tag{21}$$

where h is the displacement in time from the optimal timing, then it can use various policy strategies to effect such revision. However, in the interactive scenario, to determine the acceptability of such coordination, the concept of side payment is used. The firm or project that gains by encouraging the other firm to open earlier than its optimal timing will compensate the other firm for its loss.

In the following discussion, the derivation of the enforceable alternative available to the social coordinator under the various equilibrium conditions is based on the principle of an enforceable cooperative solution in non-cooperative games: the desired alternative optimal timing mix must be on the reaction curves of both projects (Romp, 1997). Otherwise, the projects have the incentive to unilaterally deviate from it.

When Project A is Subsequent Implementer, Project B is Prior Implementer, the social net

present value of each project has been derived as:

$$V_A\left(\frac{1}{\omega_A}\ln\frac{\rho I_A}{\overline{\Phi}_A},T_B\right)=I_A\left(\frac{\Phi_A}{\rho I_A}\right)^{\frac{\rho}{\omega_A^\Delta}}\left(\frac{\omega_A^\Delta}{\rho-\omega_A^\Delta}\right)$$

$$V_B\left(T_A,\frac{1}{\omega_B}\ln\frac{\rho I_B}{\overline{\Phi}_B}\right)=I_B\left\{\frac{\overline{\Phi}_B}{\rho I_B}\right\}^{\frac{\rho}{\omega_B}}\left(\frac{\omega_B}{\rho-\omega_B}\right)+\overline{\Phi}_B\left[\frac{\exp\left\{\left(\omega_B^\Delta-\rho\right)T_A\right\}}{\left(\rho-\omega_B^\Delta\right)}-\frac{\exp\{(\omega_B-\rho)T_A\}}{(\rho-\omega_B)}\right]$$

The joint social benefit Ω can be written as:

$$\begin{aligned}\Omega&=V_A\left(\frac{1}{\omega_A}\ln\frac{\rho I_A}{\overline{\Phi}_A},T_B\right)+V_B\left(T_A,\frac{1}{\omega_B}\ln\frac{\rho I_B}{\overline{\Phi}_B}\right)\\&=I_A\left(\frac{\Phi_A}{\rho I_A}\right)^{\frac{\rho}{\omega_A^\Delta}}\left(\frac{\omega_A^\Delta}{\rho-\omega_A^\Delta}\right)+I_B\left\{\frac{\Phi_B}{\rho I_B}\right\}^{\frac{\rho}{\omega_B}}\left(\frac{\omega_B}{\rho-\omega_B}\right)\\&\quad+\Phi_B\left[\frac{\exp\left\{\left(\omega_B^\Delta-\rho\right)T_A\right\}}{\left(\rho-\omega_B^\Delta\right)}-\frac{\exp\{(\omega_B-\rho)T_A\}}{(\rho-\omega_B)}\right]\end{aligned}\tag{22}$$

When the equilibrium point is Project A subsequent implementer/Project B prior implementer, the enforceable strategy is to move the subsequent optimal time of Project A earlier but retain the prior optimal time of Project B. In symbol, this is expressed as:

$$\Omega\left(T_{A,si}^*,T_{B,pi}^*\right)<\Omega\left(T_{A,si}^*-h_A,T_{B,pi}^*\right)\tag{23}$$

thus when financial subsidy is granted, $T_{A,si}^*-h_A$ becomes the revised subsequent optimal timing of project B due to the rate of public subsidy σ, $T_{A,si}^{*\sigma}$, However, so as not to include invalid optimal timing mix, $T_{A,si}^{*\sigma}$ should be greater than or equal to the optimal timing for prior implementation of Project B. In symbol,

$$T_{A,si}^{*\sigma}\geq T_{B,pi}^*\tag{24}$$

Thus,

$$\frac{1}{\omega_A^\Delta}\ln\left(\frac{\rho\sigma I_A}{\overline{\Phi}_A}\right)\geq\frac{1}{\omega_B}\ln\left(\frac{\rho I_B}{\overline{\Phi}_B}\right)\rightarrow\ln\left(\frac{\rho\sigma I_A}{\overline{\Phi}_A}\right)\geq\frac{\omega_A^\Delta}{\omega_B}\ln\left(\frac{\rho I_B}{\overline{\Phi}_B}\right)$$

$$\ln\left(\frac{\rho\sigma I_A}{\overline{\Phi}_A}\right)\geq\ln\left(\frac{\rho I_B}{\overline{\Phi}_B}\right)^{\frac{\omega_A^\Delta}{\omega_B}}$$

Taking the exponential of both sides:

$$\left(\frac{\rho\sigma I_A}{\overline{\Phi}_A}\right)\geq\left(\frac{\rho I_B}{\overline{\Phi}_B}\right)^{\frac{\omega_A^\Delta}{\omega_B}}$$

Therefore,

$$\sigma \geq \left(\frac{\overline{\Phi}_A}{\rho I_A}\right)\left(\frac{\rho I_B}{\overline{\Phi}_B}\right)^{\frac{\omega_A^\Delta}{\omega_B}} \tag{25}$$

However, for social acceptability of financial subsidy, the change in joint social welfare must greater than the cost of the financial subsidy, as expressed below:

$$\Omega\left(T_A^* - h_A, T_B^*\right) - \Omega\left(T_A^*, T_B^*\right) \geq \sigma I_A \tag{26}$$

In the case when equilibrium is at Project A prior implementer/Project B subsequent implementer, the respective equations for the social net present value as derived are:

$$V_A\left(\frac{1}{\omega_A}\ln\frac{\rho I_A}{\overline{\Phi}_A}, T_B\right) = I_A\left\{\frac{\Phi_A}{\rho I_A}\right\}^{\frac{\rho}{\omega_A}}\left(\frac{\omega_A}{\rho-\omega_A}\right) + \Phi_A\left[\frac{\exp\left\{\left(\omega_A^\Delta - \rho\right)T_B\right\}}{\left(\rho-\omega_A^\Delta\right)} - \frac{\exp\left\{\left(\omega_A - \rho\right)T_B\right\}}{(\rho-\omega_A)}\right]$$

$$V_B\left(T_A, \frac{1}{\omega_B}\ln\frac{\rho I_B}{\overline{\Phi}_B}\right) = I_B\left(\frac{\Phi_B}{\rho I_B}\right)^{\frac{\rho}{\omega_A^\Delta}}\left(\frac{\omega_B^\Delta}{\rho-\omega_B^\Delta}\right)$$

Thus the joint social net benefit is expressed as:

$$\begin{aligned}\Omega &= V_A\left(\frac{1}{\omega_A}\ln\frac{\rho I_A}{\overline{\Phi}_A}, T_B\right) + V_B\left(T_A, \frac{1}{\omega_B^\Delta}\ln\frac{\rho I_B}{\overline{\Phi}_B}\right)\\ &= I_A\left\{\frac{\overline{\Phi}_A}{\rho I_A}\right\}^{\frac{\rho}{\omega_A}}\left(\frac{\omega_A}{\rho-\omega_A}\right) + \overline{\Phi}_A\left[\frac{\exp\left\{\left(\omega_A^\Delta - \rho\right)T_B\right\}}{\left(\rho-\omega_A^\Delta\right)} - \frac{\exp\left\{\left(\omega_A - \rho\right)T_B\right\}}{(\rho-\omega_A)}\right]\\ &\quad + I_B\left(\frac{\Phi_B}{\rho I_B}\right)^{\frac{\rho}{\omega_B^\Delta}}\left(\frac{\omega_B^\Delta}{\rho-\omega_B^\Delta}\right)\end{aligned} \tag{27}$$

Adopting the same logic as the previous case, the enforceable cooperative solution for an improved joint social benefit is to retain the optimal timing of Project A as prior implementer and hasten the optimal timing of Project B as subsequent implementer when:

$$\Omega\left(T_{A,pi}^*, T_{B,si}^*\right) < \Omega\left(T_{A,pi}^*, T_{B,si}^* - h_B\right) \tag{28}$$

where the revised optimal timing for Project B, $T_{B,si}^* - h_B$, is equal to its revised optimal timing for subsequent implementation under the financial subsidy scheme, $T_{B,si}^{*\sigma}$. As in the previous section, σ is the rate of public subsidy. The nomenclature is changed to distinguish the formulation from that for a single, independent project.

Likewise, corollary to Equation (*24*), to exclude illogical optimal timing matches, $T_{B,si}^{*\sigma}$ should be greater or equal to the optimal prior timing of Project A.

$$T_{B,si}^{*\sigma} \geq T_{A,pi}^* \tag{29}$$

Thus,

$$\frac{1}{\omega_B^{\Delta}}\ln\left(\frac{\rho\sigma I_B}{\overline{\Phi}_B}\right)\geq\frac{1}{\omega_A}\ln\left(\frac{\rho I_A}{\overline{\Phi}_A}\right)\rightarrow\ln\left(\frac{\rho\sigma I_B}{\overline{\Phi}_B}\right)\geq\frac{\omega_B^{\Delta}}{\omega_A}\ln\left(\frac{\rho I_A}{\overline{\Phi}_A}\right)$$

$$\ln\left(\frac{\rho\sigma I_B}{\overline{\Phi}_B}\right)\geq\ln\left(\frac{\rho I_A}{\overline{\Phi}_B}\right)^{\frac{\omega_B^{\Delta}}{\omega_A}}$$

Therefore,

$$\sigma\geq\left(\frac{\overline{\Phi}_B}{\rho I_B}\right)\left(\frac{\rho I_A}{\overline{\Phi}_A}\right)^{\frac{\omega_B^{\Delta}}{\omega_A}} \tag{30}$$

For social acceptability, the cost of the financial subsidy granted to Project B must be less than or equal to the gain in joint social net benefit.

$$\Omega\left(T_{A,pi}^{*},T_{B,si}^{*}-h\right)-\Omega\left(T_{A,pi}^{*},T_{B,si}^{*}\right)\geq\sigma I_A \tag{31}$$

When the **equilibrium point is at T^{*}=0**, the respective social net present value of each project is derived as follows:

$$V_A(0,T_B)=-I_A+\frac{\overline{\Phi}_A}{(\rho-\omega_A)}+\overline{\Phi}_A\left\{\frac{\exp(\omega_A^{\Delta}-\rho)T_B}{(\rho-\omega_A^{\Delta})}-\frac{\exp(\omega_A-\rho)T_B}{(\rho-\omega_A)}\right\}$$

Similarly,

$$V_B(T_A,0)=-I_B+\frac{\overline{\Phi}_B}{(\rho-\omega_B)}+\overline{\Phi}_B\left\{\frac{\exp(\omega_B^{\Delta}-\rho)T_A}{(\rho-\omega_B^{\Delta})}-\frac{\exp(\omega_B-\rho)T_A}{(\rho-\omega_B)}\right\}$$

Joint Social Welfare

$$\begin{aligned}\Omega=&-I_A+\frac{\overline{\Phi}_A}{(\rho-\omega_A)}+\overline{\Phi}_A\left\{\frac{\exp(\omega_A^{\Delta}-\rho)T_B}{(\rho-\omega_A^{\Delta})}-\frac{\exp(\omega_A-\rho)T_B}{(\rho-\omega_A)}\right\}\\&-I_B+\frac{\overline{\Phi}_B}{(\rho-\omega_B)}+\overline{\Phi}_B\left\{\frac{\exp(\omega_B^{\Delta}-\rho)T_A}{(\rho-\omega_B^{\Delta})}-\frac{\exp(\omega_B-\rho)T_A}{(\rho-\omega_B)}\right\}\end{aligned} \tag{32}$$

When the joint social benefit W is maximized at *T=0*, then this case is naturally coordinated. Otherwise, to delay opening of service, the social coordinator have to impose taxes and regulate pricing.

In the case when there are **multiple synchronized equilibrium points**, the respective social net present value of the projects may be formulated as:

$$V_A(T_B,T_B)=-I_A\exp(-\rho T_B)+\frac{\overline{\Phi}_A}{(\rho-\omega_A^{\Delta})}\exp(\omega_A^{\Delta}-\rho)T_B$$

$$V_B(T_A, T_A) = -I_B \exp(-\rho T_A) + \frac{\overline{\Phi}_B}{(\rho - \omega_B^{\Delta})} \exp(\omega_B^{\Delta} - \rho) T_A$$

Joint social welfare:

$$\begin{aligned} \Omega = & -I_A \exp(-\rho T_B) + \frac{\overline{\Phi}_A}{(\rho - \omega_A^{\Delta})} \exp(\omega_A^{\Delta} - \rho) T_B \\ & -I_B \exp(-\rho T_A) + \frac{\overline{\Phi}_B}{(\rho - \omega_B^{\Delta})} \exp(\omega_B^{\Delta} - \rho) T_A \end{aligned} \tag{33}$$

8. BOUNDED RATIONALITY AND THE ROLE OF GOVERNMENT

The strongest assumption in the derivation of the models for coordination in this chapter is that the players, or project proponents are instrumentally rational, that is they are 'solely interested in satisfying their own preferences or desires'. Thus they are always assumed to act in their self-interest. This assumption is also one of the most criticized against game theory, since it cannot fully explain the instance when an individual deviates from the seemingly rational behavior of seeking to maximize his gain, he/she is considered irrational (Romp, 1997). An alternative definition put forth to 'explain' this irrational behavior is 'bounded rationality' (Milgrom, et.al., 1992). According to this concept, individuals have limited computational ability. In reality, people are not omniscient or perfectly far-sighted and thus have limited capacity to foresee all the things that might matter for them. From the perspective of optimal investment timing, this boundedness may be expressed in managers perceiving present and future net benefit as equal. Thus, extremely bounded managers may choose to implement now or never.

In a contractual situation, formal or relational, bounded rationality can give rise to the following actions: opportunistic behavior, including reneging, imperfect commitment, and self-interested misbehavior (moral hazard) brought about by private information. In this research, the most significant of the actions listed are opportunistic behavior and imperfect commitment from the light that the projects are interdependent and the implementation of one would affect the other positively. Reneging from the agreed upon schedule of implementation may affect the prior implementer. Thus, the importance of the role of the government as a coordinator is enhanced under this condition.

Another important check on ex-post opportunism is the concern of the institution or private firm with its reputation. Depending on the 'frequency of similar transactions, the horizon over which similar transactions are expected to occur, and the transaction's profitability', this may even achieve the same results as actual commitment. Since the firms or institutions involved in the implementation of transport infrastructure are assumed to play this dynamic one-off game several times with different 'opponents', then getting a bad reputation that reduces future possibilities for profitable transactions can limit reneging.

On a final note, in a world of cost and incomplete contracting, trust is crucial to realizing many transactions. This is true for the private firms or institutions involved as well as the government. Building and maintaining their credibility is one area that governments in developing countries must work on.

9. SUMMARY

In this paper, the concept of optimal investment timing is extended to an interactive scenario. Using a two-project situation, the Net Present Value for two projects that are complementary was derived for various optimal timing decisions. The linking variable between the projects was integrated in the demand growth rate. At any time, one project has four possible choices, depending on the opening of service of the other project. These choices are: implement now, implement subsequent to the other project (hence called subsequent implementer), implement prior to the other project (called prior implementer), or synchronize implementation with the other project. Reaction curves of the firms under various conditions and the equilibrium conditions were derived using the concept of Nash Equilibrium for non-cooperative games. There were six possible equilibrium conditions established. Due to a variety of cases, coordination strategies are considered to be dependent on project characteristics and conditions.

It was, however, emphasized that in choosing a coordinated timing mix, the *social coordinator* must choose an *optimal timing mix found on the reaction curves of the projects, otherwise it will not be binding since each proponent will have an incentive to unilaterally deviate from it.* The limiting factor for coordination using a multiple project scenario was conceptualized as the willingness of the project that will gain to compensate the loss incurred by the other project. This is a concept borrowed from *side payment*, often used in environmental economics.

One important issue that must be emphasized is that reaction functions were derived assuming *instrumental rationality*, i.e., individuals are only concerned with satisfying their own needs. However, in the presence of *bounded rationality*, the reactions or decisions of the project proponents may not be as straightforward as the models suggest. Thus, the social coordinator must also address opportunistic behavior, including reneging, and imperfect commitment arising from bounded rationality. Since it is the role of the government to coordinate the interdependent projects, then it must also be concerned with its credibility for in the presence of bounded rationality and thus limited foresight for future events, trust is of absolute necessity.

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