Sequencing of Club Enlargement: "big bang", "gradualism," and internal reform

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WORKING PAPER SERIES (ISSN 1211-3298)
Electronic Version

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Abstract

In an incomplete contract framework, I analyse how a club chooses its enlargement strategy in the presence of congestion. The club faces two waves of applicants. The applicants are homogeneous within each wave but differ in their conformity to the club's standards across waves. For each wave, the club chooses between an early entry offer, when the club can enforce the applicant's reform, and a late entry offer, when the applicant has to reform itself in order to be admitted. In addition, the club undertakes its own internal reform which, if successful, can eliminate congestion. I show that the club uses the "gradualism" approach (admitting waves sequentially) when the waves substantially differ in their compliance with the club's standards, and the "big bang" approach (admitting waves simultaneously) otherwise. Moreover, the club never admits a less advanced wave before a more advanced one.

Abstrakt

V rámci neúplných kontraktů analyzuji, jak klub volí strategii rozšiřování za přítomnosti kongesce. Klub jedná s dvěma vlnami uchazečů. Uchazeči jsou homogenní uvnitř každé vlny, ale mezi vlnami se liší v míře shody s klubovými standardy. Klub nabízí každé vlně buď okamžitý vstup, při němž klub může donutit uchazeče k reformě, nebo odložený vstup, při němž uchazeč musí uskutečnit vlastní reformu, aby byl přijat. Kromě toho, klub podniká svou vnitřní reformu, která, je-li úspěšná, eliminuje kongesci. Ukazuji, že klub používá přístupu „gradualistického" (přijímá vlny postupně), pokud se vlny významně liší ve splnění požadavků klubu, a přístupu „velkého třesku" (přijímá vlny současně) v opačném případě. Klub navíc nikdy nepřijímá méně pokročilou vlnu před vlnou pokročilejší.

JEL classification: D71; P21

Keywords: Transition; Club theory; Incomplete contracts.

* I wish to thank Gérard Roland, Andreas Ortmann, Milan Horniaček, and Guido Friebel for helpful comments..

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1 Introduction

Voluntary groups whose members derive mutual benefit from membership, or clubs, play an increasingly larger role in today's world. A prominent feature of many clubs (ranging from discussion groups on the Internet to major international organisations) is the club's exclusive right to admit new members, which results from obstacles that render unlimited expansion of the club inadvisable or even impossible. The traditional example of such an obstacle used in the economics literature on clubs is congestion in the consumption of the club good (Cornes and Sandler, 1986). Another obstacle is heterogeneity among members. For example, Baldwin (1995) argues that the demand for integration (and, therefore, the optimal club size) decreases as the diversity among potential members increases.

An important aspect of club enlargement, which has received comparatively little attention theoretically (albeit much attention in reality), is the optimal timing of the admission of new members. Burkart and Wallner (2000) develop an incomplete contract model in which they analyse when and whether the club should admit an applicant whose type is given by its initial levels of wealth and compliance with the club's standards. Specifically, the club offers the applicant either an early entry offer (which allows the applicant to join the club immediately and allows the club to enforce the applicant's reform) or a late entry offer (under which the club admits the applicant only after it complies with the standards). The club may also reject the applicant. Burkart and Wallner find that while relatively wealthy applicants are allowed to enter early, the club follows the so-called reversed admittance order for poor applicants by offering early entry to less advanced applicant types and late entry to more advanced ones. Kúnin (2000) shows that this result depends on the club's payoffs: if they differ between the late entry of a reformed applicant and the early entry of an initially unreformed applicant, then the phenomenon of reversed admittance order does not occur.

In this paper, I introduce congestion into the models of Burkart and Wallner (2000) and Kúnin (2000). I assume that once all admitted applicants have acceded, each member of the club incurs congestion costs that increase with the club's size after enlargement. In addition, between the dates of accession of early and late entrants, the club undertakes an internal reform that, if successful, eliminates the congestion. However, the probability of success of the internal reform decreases as the club's size after the early entrants' accession increases. As a result, the club's payoff is no longer additive in applicants, which means that the club cannot consider each applicant separately.

I assume that the club faces two waves of applicants which may differ in size, and compliance with the club's standards may differ between (though not within) waves. This means that the club has to undertake three actions: the internal reform and the integration of the two waves. Since integration can also be viewed as a kind of reform, the problem faced by the club is an example of the problem of reform sequencing, well-known in transition economics (Roland, 2000).

The most important application of the present model is the eastward enlargement of the European Union (EU). In fact, the key features of my model are motivated by this process. First, the EU had to devise an enlargement strategy, i.e., it had to decide when the candidates should accede and how many of them should be allowed to enter at a particular date. Enlargement in waves seems to be the EU's current enlargement strategy.

Second, the EU needs to resolve the problem of the institutional paralysis caused by the non-sustainability of the current decision-making rules. There seems to be general consensus that an internal reform of decision-making rules will be much more difficult to implement once some or all of the accession candidates have acceded.

The EU generally requires that the accession candidates undertake all necessary reforms to comply with the EU standards by their accession time. These reforms (e.g., adopting EU environmental regulations), however, are costly to the candidate countries, and they would be suboptimal were it not for EU accession. Because the accession candidates tend to be resource constrained, their reforms have to be (partially) financed by the EU. Indeed, Senior Nello and Smith (1998) estimate that by 2006, 30% of all transfers through the EU's Structural Funds will have been spent for enlargement purposes.

In the present model it is assumed that enlargement is preferred to no enlargement, i.e., that the main issue is how the enlargement should be scheduled with respect to the club's internal reform rather than whether there should be any enlargement at all. While some studies dispute whether the economic benefits of EU integration exceed the costs of adjustment for the accession countries (e.g., Mortensen and Richter, 2000), the more common opinion seems to be that the costs of adjustment to EU standards are outweighed by the political benefits of the enlargement (e.g., Baldwin, Francois and Portes, 1997, claim that the eastern enlargement is a "phenomenally good bargain" for both incumbent and accession countries).

This paper is organised as follows. I describe the model in Section 2, and present the solution to the club's sequencing problem in Section 3. An extension of the model, allowing for some or all applicants being rejected by the club, is discussed in Section 4. Section 5 concludes. All mathematical proofs and figures may be found in the appendices.

2 The model

2.1 Framework

The players in the model are a club, which has the exclusive right to admit new members, and two waves of applicants for club membership. The applicants are assumed to be homogeneous within each wave but may differ across waves in their conformity to the club's standards. The whole game takes place in a single period, starting at time 0 and ending at time 1. The discount rate between time 0 and time 1 is $\delta \in (0, 1]$.

The game begins at time 0 by the club determining whether each wave is going to join the club *early* (at time 0) or *late* (at time 1.) Then the club offers the applicants of each wave to join at the time chosen for the wave, conditional on meeting the club's standards at time 1. Still at time 0, the applicants either accept or reject the offer. Those who accepted the offer to join the club early, accede immediately.

Between time 0 and time 1, all applicants who accepted the club's offer reform themselves in order to meet the club's standards by time 1. During the same period, the club undertakes its internal reform aimed at eliminating congestion costs (such as communication and decision making) in the club after enlargement. The club's internal reform may succeed or fail, with the probability of success decreasing as the club's size increases.

At time 1, the applicants who accepted the offer to enter the club late accede, and congestion costs materialise if the club's internal reform has failed.

2.2 The applicants

Applicant wave i ($i = 1, 2$) consists of $n_i > 0$ applicants that act independently. Every applicant in wave i is characterised by its reform distance (status) d_i, which equals the net cost of investment an applicant should make in order to meet the club's standards. The applicants' investment in their reform status is relation-specific, and even if this investment yields some direct gains to the applicants, these gains do not cover the whole cost of the applicants' reform, so that the net cost is positive: $d_i > 0$. Thus, the only reason why the applicants should reform is that they are club members (early entrants) or wish to enter the club (late entrants.)

The applicants are resource constrained, which means that they have no resources of their own and thus depend on subsidies (transfers) from the club. When an applicant receives a transfer from the club at time 0, it decides on how much of the transfer is spent on the applicant's reform status, and the rest is spent on consumption. An applicant that is admitted to the club receives a non-transferable membership benefit π at the time of accession. All applicants have the same linear utility function (in consumption), $u(x) = x$, and their total utility is additive in consumption and club accession.

2.3 The club

The club consists of $n_0 > 0$[1] homogeneous members and acts as a single body. At time 0, for each wave of applicants the club makes the following decisions. First, the club chooses the time of accession of the wave, which can be early (time 0) or late (time 1). Second, the club chooses the value of subsidy $s_i \geq 0$ transferred to each applicant of wave i at time 0. Finally, the club chooses the value of reward $r_i \geq 0$ transferred to each applicant of wave i at date 1, provided that this applicant has become a club member. (Since the waves are homogeneous, it is assumed that the club cannot discriminate among members of a wave, though the club's decision may differ across waves.) Thus, the offer made to a wave i applicant consists of the time of accession and the two transfers, s_i and r_i.

The club can make two types of offers: early, when the applicant is offered to join at date 0, and late, when the applicant is offered to join at date 1. If the club makes an *early* offer to an applicant and the offer is accepted, then the applicant becomes a club member immediately (at time 0). In this case, the club can perfectly control how the subsidy is spent so that the applicant's investment in reform status is sufficient to have met the club's standards by time 1. If the club makes a *late* offer to an applicant and the offer is accepted, then the applicant becomes a club member at time 1, contingent on meeting the club's standards at that date. However, the club has no enforcement power over non-members, so it cannot control how an applicant who received and accepted a late entry offer spends the subsidy.

Since there are two applicant waves and each wave's applicants can be offered either an early or a late entry, the club's strategies can be divided into four classes. Two of these classes include "big bang" strategies, wherein both waves are offered to enter at the same moment. These classes are "early big bang" (both waves receive an early entry offer) and "late big bang" (both waves receive a late entry offer). The other two classes include "gradualism" strategies, wherein the waves are offered to enter at different moments. These classes are "gradualism-1" and "gradualism-2" where '1' and '2' stand for the wave that receives the early entry offer.

At time 1, the club receives a payoff of $\Pi^R > 0$ per each new member whose investment in reform status has been sufficient to comply with the club's standards. By construction, late entry offers are conditional on an applicant's investment in its reform status. As regards the early entrants, who enter unreformed, they may remain unreformed at date 1 only if the club's subsidy was insufficient to cover the cost of reform. I assume that this does not occur, i.e., that it is never profitable for the club to have an unreformed member at date 1 so that the following assumption holds.

[1] Though the size parameters n_0, n_1, n_2 are typically interpreted as numbers of members, other interpretations are possible. For example, they may stand for GDPs or for numbers of votes, so in general n_i does not have to be a natural number.

Assumption 1 (No unreformed members) *All offers made by the club involve meeting the club's requirements by the applicants.*

In addition, at time 0 the club receives an immediate payoff of $\Pi^I - \alpha d$ per each applicant that is admitted early and has reform status d, where $\Pi^I > 0$ and $\alpha > 1$. This means that the club's immediate gains from accepting an applicant early decrease in the applicant's reform status. These gains can be represented as the gross payoff Π^I from having a new member less the costs of having a non-complying member between time 0 and time 1, αd. The assumption that $\alpha > 1$ means that these costs increase faster than the reform distance d itself.

2.4 The club's internal reform

Between time 0 and time 1 the applicants reform themselves to meet the club's standards. In its turn, the club undertakes its own (internal) reform. This internal reform is aimed at reducing costs of communication and decision making in a larger club, or, in other words, at alleviating *congestion*. Unlike the applicants' reforms whose success solely depends on the applicants' investment in their reform status, the internal reform may succeed or fail depending on the size of the club at time 0 after all early entrants accede, N_0. I assume that the larger the club, the worse the prospects of the internal reform, i.e., that the probability of failure of the internal reform, $q = q(N_0) \in (0, 1)$, is an increasing function. This reflects the fact that it is more difficult to reach a consensus in a larger club, especially when unanimity is required in decision making.

As is mentioned above, the club's strategies are divided into four classes, and these classes differ in N_0. Namely, for "early big bang" $N_0 = n_0 + n_1 + n_2$, for "late big bang" $N_0 = n_0$, for "gradualism-1" $N_0 = n_0 + n_1$, and for "gradualism-2" $N_0 = n_0 + n_2$. The probability of internal reform failure is the lowest, $q_L = q(n_0)$, for "late big bang" and the highest, $q_E = q(n_0 + n_1 + n_2)$, for "early big bang." The "gradualism" probabilities, $q_G = q(n_0 + n_1)$ and $q_R = q(n_0 + n_2)$, lie between q_E and q_L. Consider the increase in the probability of failure that occurs when wave 2's accession time is changed from time 1 to time 0, other things being equal. If wave 1 accedes *late*, then this increase equals $q_R - q_L$, and if wave 1 accedes *early*, then this increase equals $q_E - q_G$. I suppose that the larger the body to which a wave is added, the smaller the increase in the probability of internal reform failure, i.e., that the function $q(N + n) - q(N)$ decreases in N for any positive n. This amounts to the following assumption.

Assumption 2 (Concavity of probability) *The probability of internal reform failure, $q(N)$, is a strictly concave function of N for $N > n_0$. In particular, the inequalities $q_R - q_L > q_E - q_G$ and $q_G - q_L > q_E - q_R$ hold.*

2.5 Congestion

If the internal reform succeeds, the payoffs of all players remain unchanged. If the internal reform fails, then at time 1 each (incumbent or new) member of the club suffers a utility loss of cN_1, where N_1 is the size of the club after all late entrants accede and $c > 0$. Thus, the total loss incurred by the incumbents if the internal reform fails equals CN_1, where $C = cn_0$.

The congestion costs are assumed to be not too high in relation to the membership benefits.

Assumption 3 (Membership benefits) $\pi > cN_1$.

The congestion costs per member equal cN_1 and are incurred when the internal reform fails. For an early entrant, the discounted value of the expected congestion costs equals δqcN_1, which is less than cN_1 since $\delta \in (0, 1]$ and $q \in (0, 1)$. Hence, Assumption 3 means that for an early entrant, the membership benefits π exceed the discounted value of the maximal expected congestion costs. For a late entrant who meets the club's standards, the gross payoff at time 1 is not less than π (since the transfers r are non-negative), and the congestion costs equal zero when the club's internal reform succeeds and cN_1 when it fails. Thus, Assumption 3 also means that for any applicant with a late entry offer, *ex post* gains from club membership exceed *ex post* congestion costs whether or not the club's internal reform succeeds. Therefore, it never happens that it is profitable for an applicant to accept a late offer *ex ante*, but it is not profitable to enter the club *ex post* due to congestion when the internal reform fails.

In other words, Assumption 3 implies that the issue of *applicant commitment* does not occur in the model. The issue of *club commitment* does not occur either because the club only has two options regarding each applicant, early and late entry (if the club has an option to reject an applicant completely, as in Section 4, then the issue of club commitment becomes relevant). The following inference can be made.

Corollary 1 *If Assumptions 1 and 3 hold, then all offers made by the club imply that the applicants eventually join the club.*

This corollary means that the problem faced by the club is basically a *sequencing* problem. Namely, the club has to schedule the accession of each wave, which itself can be viewed as a kind of reform, with respect to the internal reform. Corollary 1 also implies that the size of the club at time 1 is $N_1 = n_0 + n_1 + n_2$ regardless of the strategy chosen by the club.

2.6 Summary of the game

The game proceeds as follows.

1. In the beginning, the club decides on its enlargement strategy, i.e., on when each wave is offered to join the club and on the transfers s_i and r_i, $i = 1, 2$.

2. The applicants simultaneously and independently decide whether to accept or to decline the offers received.

3. Those applicants who have received an early entry offer and accepted it accede to the club and realise the accession payoff π, while the club realises the immediate payoff $\Pi^I - \alpha d$ per each early entrant with reform status d.

4. The club transfers the subsidy s_i to each applicant in wave i who accepted the offer made.

5. Still at time 0, all applicants accepting the club's offers decide on investment in their reform status, with the club controlling the early entrants' decisions.

6. Between time 0 and time 1, the club attempts to reform itself. The internal reform succeeds with probability $1 - q(N_0)$ and fails with probability $q(N_0)$.

7. At time 1, the applicants who received and accepted a late entry offer and have met the club's standards, accede and realise the accession payoff.

8. The club transfers the reward r_i to each applicant in wave i who has become a club member.

9. The incumbent members realise payoffs Π^R per each reformed applicant. (There are no unreformed applicants in the club at time 1 by Assumption 1.)

10. If the internal reform has failed, the congestion costs are realised.

3 Results

3.1 Optimal transfers

The aggregate present discounted value of the transfers the club makes to an applicant equals $s+\delta r$, where s is the subsidy at time 0 and r is the reward at time 1. The club wants to minimise this value subject to the constraint of Assumption 1. Thus, the transfer at time 0 should be sufficient (*feasible*) for the applicant to reform itself, i.e., $s \geq d$, and the pair (s, r) should satisfy the applicant's *incentive compatibility* (IC) constraints. (These constraints differ for early and late entry.)

If an applicant receives an *early* entry offer with payments (s^E, r^E), and accepts it, then the applicant's payoff at time 0 equals $\pi + s^E - d$ (the applicant realises its membership benefits, receives the transfer s^E but then the club forces the applicant to invest in its reform status, which costs d). At time 1 the applicant receives the transfer r^E, and incurs the congestion costs cN_1 with probability $q = q(N_0)$. Thus, the total discounted expected payoff of the applicant when it accepts an early entry offer equals

$$\pi + s^E - d + \delta r^E - \delta qcN_1. \tag{1}$$

If the applicant *rejects* an early entry offer, its payoff equals zero, so incentive compatibility requires that (1) is nonnegative. Since $s^E \geq d$ by Assumption 1 and $r^E \geq 0$, (1) is nonnegative when $\pi - \delta qcN_1$ is nonnegative, which holds by Assumption 3. Thus, the minimal possible values of transfers, $s^E = d$ and $r^E = 0$, are sufficient for the applicant to accept an early entry offer.

If an applicant receives a *late* entry offer with payments (s^L, r^L), then there are three options. First, the applicant may accept the offer and invest in reform status. Second, the applicant may accept without investing (and without being admitted to the club at time 1). Third, the applicant may reject the offer. Since the investment is relation-specific, the applicant will not invest more than required, which implies the investment of exactly d in the first case and no investment at all in the second one.

If the applicant accepts a late entry offer *and invests*, then the payoff at time 0 equals $s^L - d$ and the expected payoff at time 1 equals $\pi + r^L - qcN_1$. Thus, the total payoff in this case equals

$$s^L - d + \delta\pi + \delta r^L - \delta qcN_1. \tag{2}$$

If the applicant accepts a late entry offer *and does not invest*, then the payoff at time 0 equals s^L, and at time 1 the applicant is not admitted to the club so that the payoff is zero and the total payoff equals s^L. If the applicant *rejects* a late entry offer, then the payoff is zero. By Assumption 1, $s^L \geq d > 0$ so that the rejection of a late entry offer is strictly dominated by its acceptance without investment. Thus, a late entry offer is accepted with investment if (2) exceeds s^L, i.e., if

$$\delta r^L \geq d - \delta\pi + \delta qcN_1. \tag{3}$$

Note that this incentive compatibility constraint does not contain s^L due to the linearity of the applicant's utility function. The club will not transfer more than $s^L = d$ at time 0, and the transfer at time 1 will equal $r^L = 0$ if the right-hand side of (3) is negative, and δr^L will equal the right-hand side of (3) if it is positive. The critical value of reform distance is equal to $\delta(\pi - qcN_1)$. If the applicant is more advanced (i.e., if d is less than the critical value), then the club does not have to oversubsidise the applicant in the case of late entry, and if the applicant is less advanced (i.e., if d exceeds the critical value), then such oversubsidisation takes place.

Thus, the club uses the following transfers.

Proposition 1 *Let Assumptions 1 and 3 hold. Then, making an offer to an applicant with reform distance d, the club always includes the transfer of $s^E = s^L = d$ at time 0 in both early and late entry offers. At time 1, the club transfers $r^E = 0$ in early entry offers, and the transfer in late entry offers is determined by*

$$\delta r^L = \delta r^L(d, q) = \begin{cases} 0, & d \leq \delta(\pi - qcN_1), \\ d - \delta(\pi - qcN_1), & d > \delta(\pi - qcN_1). \end{cases} \tag{4}$$

3.2 Optimal admittance strategies

Let Assumptions 1 to 3 hold, and let the club's offer to an applicant include transfers s and r. Consider the club's payoffs associated with this applicant. At time 0, this payoff equals $-s+\Pi^I-\alpha d$ in the case of an early entry offer and $-s$ in the case of a late entry offer, and at time 1 this payoff equals $\delta\Big(\Pi^R-r\Big)$ in both cases. The total expected payoff of the club equals the sum of the payoffs associated with every applicant minus expected congestion costs, which equal $\delta qCN_1=\delta qcn_0N_1$.

Thus, the club's total expected payoffs are the following, taking into account Proposition 1. If the club employs an "early big bang" strategy, then the club's payoff equals

$$W_E=n_1\Big(-d_1+\Pi^I-\alpha d_1+\delta\Pi^R\Big)+n_2\Big(-d_2+\Pi^I-\alpha d_2+\delta\Pi^R\Big)-\delta q_ECN_1,$$

for a "late big bang" strategy

$$W_L=n_1\Big(-d_1+\delta\Pi^R-\delta r^L(d_1,q_L)\Big)+n_2\Big(-d_2+\delta\Pi^R-\delta r^L(d_2,q_L)\Big)-\delta q_LCN_1,$$

for a "gradualism-1" strategy

$$W_G=n_1\Big(-d_1+\Pi^I-\alpha d_1+\delta\Pi^R\Big)+n_2\Big(-d_2+\delta\Pi^R-\delta r^L(d_2,q_G)\Big)-\delta q_GCN_1,$$

and for a "gradualism-2" strategy

$$W_R=n_1\Big(-d_1+\delta\Pi^R-\delta r^L(d_1,q_R)\Big)+n_2\Big(-d_2+\Pi^I-\alpha d_2+\delta\Pi^R\Big)-\delta q_RCN_1.$$

The club prefers "early big bang" to "gradualism-1" iff $W_E\geq W_G$, i.e., iff

$$n_2\Big(\Pi^I-\alpha d_2+\delta r^L(d_2,q_G)\Big)\geq\delta(q_E-q_G)CN_1. \tag{5}$$

The left-hand size of (5) is a decreasing function of d_2 because $\partial\Big(\delta r^L(d,q)\Big)/\partial d\leq 1$ according to (4) and $\alpha>1$. Thus, the club prefers accepting both waves early to accepting wave 1 early and wave 2 late iff wave 2's reform distance does not exceed the threshold value, which equals

$$d_2^{EG}=\frac{n_2\Pi^I-\delta(q_E-q_G)CN_1}{n_2\alpha} \tag{6}$$

if $d_2^{EG}\leq\delta(\pi-q_GcN_1)$, i.e., if the applicant's late-entry incentive compatibility constraint is not binding, and

$$d_2^{EG}=\frac{n_2\Big(\Pi^I-\delta\pi+\delta q_GcN_1\Big)-\delta(q_E-q_G)CN_1}{n_2(\alpha-1)} \tag{7}$$

otherwise.

The club prefers "gradualism-2" to "late big bang" iff $W_R\geq W_L$, i.e., iff

$$n_2\Big(\Pi^I-\alpha d_2+\delta r^L(d_2,q_L)\Big)-n_1\Big(\delta r^L(d_1,q_R)-\delta r^L(d_1,q_L)\Big)\geq\delta(q_R-q_L)CN_1. \tag{8}$$

Again, the left-hand size of (8) decreases in d_2 and the maximal value of d_2 for the club to prefer accepting wave 2 early and wave 1 late to accepting both waves late equals

$$d_2^{RL}(d_1) = \frac{n_2\Pi^I - \delta(q_R - q_L)CN_1 - n_1\Delta}{n_2\alpha} \tag{9}$$

if $d_2^{RL}(d_1) \leq \delta(\pi - q_L cN_1)$ and

$$d_2^{RL}(d_1) = \frac{n_2\Big(\Pi^I - \delta\pi + \delta q_L cN_1\Big) - \delta(q_R - q_L)CN_1 - n_1\Delta}{n_2(\alpha - 1)} \tag{10}$$

otherwise, where $\Delta = \Delta(d_1) = \delta r^L(d_1, q_R) - \delta r^L(d_1, q_L) =$

$$= \begin{cases} 0, & d_1 \leq \delta(\pi - q_R cN_1), \\ d_1 - \delta(\pi - q_R cN_1), & \delta(\pi - q_R cN_1) \leq d_1 \leq \delta(\pi - q_L cN_1), \\ \delta(q_R - q_L)cN_1, & d_1 \geq \delta(\pi - q_L cN_1) \end{cases}$$

is nonnegative and non-decreasing in d_1.

In the same way it can be shown that the club prefers "early big bang" to "gradualism-2" iff $d_1 \leq d_1^{ER}$ where

$$d_1^{ER} = \frac{n_1\Pi^I - \delta(q_E - q_R)CN_1}{n_1\alpha}$$

if $d_1^{ER} \leq \delta(\pi - q_R cN_1)$ and

$$d_1^{ER} = \frac{n_1\Big(\Pi^I - \delta\pi + \delta q_R cN_1\Big) - \delta(q_E - q_R)CN_1}{n_1(\alpha - 1)}$$

otherwise, and that the club prefers "gradualism-1" to "late big bang" iff $d_1 \leq d_1^{GL}(d_2)$ where

$$d_1^{GL}(d_2) = \frac{n_1\Pi^I - \delta(q_G - q_L)CN_1 - n_2\bar{\Delta}}{n_1\alpha}$$

if $d_1^{GL} \leq \delta(\pi - q_L cN_1)$ and

$$d_1^{GL}(d_2) = \frac{n_1\Big(\Pi^I - \delta\pi + \delta q_L cN_1\Big) - \delta(q_G - q_L)CN_1 - n_2\bar{\Delta}}{n_1(\alpha - 1)}$$

otherwise, where $\bar{\Delta} = \bar{\Delta}(d_2) = \delta r^L(d_2, q_G) - \delta r^L(d_2, q_L)$.

Lemma 1 *Let Assumptions 1 to 3 hold. Then* $d_2^{EG} > d_2^{RL}(d_1)$ $\forall d_1$ *and, similarly,* $d_1^{ER} > d_1^{GL}(d_2)$ $\forall d_2$.

The proof of this lemma is in Appendix A. Figure 1 illustrates the lemma by showing graphs of d_2^{EG} (above) and $d_2^{RL}(d_1)$ (below) in the (d_1, d_2)-plane.

Thus, the club applies "gradualism-1" iff $d_2 > d_2^{EG}$ and $d_1 \leq d_1^{GL}(d_2)$, and "gradualism-2" iff $d_1 > d_1^{ER}$ and $d_2 \leq d_2^{RL}(d_1)$. If $d_1 \leq d_1^{ER}$, $d_2 \leq d_2^{EG}$, and either $d_1 \leq d_1^{GL}(d_2)$ or $d_2 \leq d_2^{RL}(d_1)$, then the club applies "early big bang." If $d_1 > d_1^{GL}(d_2)$, $d_2 > d_2^{RL}(d_1)$, and either $d_1 > d_1^{ER}$ or $d_2 > d_2^{EG}$, then the club applies "late big bang." The remaining case is $d_1^{GL}(d_2) < d_1 \leq d_1^{ER}$ and $d_2^{RL}(d_1) < d_2 \leq d_2^{EG}$, when the club chooses between the two "big bang" options. The club prefers "early big bang" to "late big bang" iff $W_E \geq W_L$, i.e., iff

$$n_1\Big(\Pi^I - \alpha d_1 + \delta r^L(d_1, q_L)\Big) + n_2\Big(\Pi^I - \alpha d_2 + \delta r^L(d_2, q_L)\Big) \geq \delta(q_E - q_L)CN_1. \qquad (11)$$

The left-hand side of (11) is decreasing in both d_1 and d_2, so that the boundary between these options is a decreasing function in the (d_1, d_2)-plane.

The optimal choices of the club are illustrated in Figure 2, where it is additionally assumed that $d_2^{RL}(d_1) > 0$ and $d_1^{GL}(d_2) > 0$ for all d_1, d_2. The labels 'E', 'L', 'G', and 'R' denote the sets of parameters for which the club's approach is "early big bang," "late big bang," "gradualism-1," and "gradualism-2," respectively. The dashed line is $d_1 = d_2$, i.e., it corresponds to the waves being equally advanced.

Thus, the optimal admittance (sequencing) strategy of the club is summarised by the following proposition.

Proposition 2 *Let the two waves of applicants be similar in size. Then in the presence of internal reform, the club uses the "gradualism" approach only if one of the waves is advanced whereas the other one is much less advanced, i.e., if the reform distance substantially differs across the waves. In this case the more advanced wave is admitted early and the less advanced wave is admitted late. Otherwise, the club uses the "big bang" approach, with both waves admitted early when they are both advanced and late when they are both less advanced.*

The requirement for the waves to be similar in size ($n_1 \approx n_2$) means that the threshold values are also approximately the same so that the whole situation is not exceedingly asymmetric. In this case, when the waves are *homogeneous in size*, the club applies "gradualism" if they are *heterogeneous in reform status*. The case in which the waves are heterogeneous in size is depicted in Figure 3 and discussed later in this section (under the "Admittance order" heading). In this case it is possible that the club applies a "gradualism" strategy when the wave receiving a late offer is much larger but only slightly less advanced than the other one.

Proposition 2 implies that the club does not consider the applicants independently. The reason for this is that the total club's payoff is not additive (i.e., it does not equal the sum of the payoffs associated with every applicant) in the presence of the internal reform and congestion. Indeed, if there is no congestion, then $c = 0$ and $C = 0$. This means that $r^L(d, q)$ does not depend on q, so that the inequalities (5) and (8) coincide and $\Delta \equiv 0$. Hence, the threshold values are equal, and the club treats each applicant individually as in Burkart and Wallner (2000).

Corollary 2 *Let Assumption 1 hold. Let there be no congestion ($c = 0$) or let the internal reform succeed with certainty ($q(n) \equiv 0$). Then the club treats every applicant independently and, facing an applicant with reform distance d, offers an early entry offer to this applicant if $d \leq \bar{d}$ and a late entry offer otherwise, where*

$$\bar{d} = \begin{cases} \Pi^I/\alpha, & \Pi^I - \alpha\delta\pi \leq 0, \\ (\Pi^I - \delta\pi)/(\alpha - 1), & \Pi^I - \alpha\delta\pi > 0. \end{cases} \tag{12}$$

This corollary simply restates the result obtained in Kúnin(2000) as a limiting case of Lemma 1 and Proposition 2. The threshold values in (12) are derived from (6) and (7), or from (9) and (10) when $c = C = 0$ or when $q_X \equiv 0$.

The most important assumptions underlying the result of Proposition 2 are Assumption 2 and the assumption that $\alpha > 1$. If the probability of internal reform success, $p(N)$, is not strictly convex as Assumption 2 demands but just weakly convex, then it may happen that $q_R - q_L = q_E - q_G$ so that the claim of Lemma 1 holds with weak inequalities instead of strict ones. If $p(N)$ is locally concave[2] for some $N \in (n_0, n_0 + n_1 + n_2)$, then the results may not hold. In the latter case, the club's choice among enlargement strategies may look as in Figure 4, i.e., the club may apply the "big bang" approach if the waves are either both advanced (both d_1 and d_2 are small) or both less advanced (both d_1 and d_2 are large), and the "gradualism" approach otherwise.

The meaning of the assumption that $\alpha > 1$ is the following. Let the club face an applicant with reform distance d. If the applicant is offered early entry, then the club's payoff associated with the applicant equals $-d + \Pi^I - \alpha d + \delta\Pi^R$, and if the applicant is offered late entry, then this payoff equals $-d + \delta\Pi^R - \delta r^L(d, q)$, according to Proposition 1. Let $\bar{s}^E = d - \Pi^I + \alpha d - \delta\Pi^R$ and $\bar{s}^L = d + \delta r^L(d, q) - \delta\Pi^R$ be the "net transfers" from the club to the applicant. Then $\partial\bar{s}^E/\partial d = 1 + \alpha > 2$ and $\partial\bar{s}^L/\partial d \leq 2$. Thus, $\alpha > 1$ implies that the "net transfers" grow (in the applicant's reform distance) faster in the case of early entry than in the case of late entry.

3.3 Comparative statics

Let Assumptions 1 to 3 hold. Consider how the threshold values in Lemma 1 react to changes in the model parameters. The parameters in question are Π^R, Π^I, π, α, δ, c, and the size parameters. In all cases I assume that the changes in the parameters are small. Let "case A" denote the situation in which the thresholds are determined by (6) or (9) (or by the corresponding formulae for d_1-thresholds), and let "case B" denote the situation in which the thresholds are determined by (7) or (10).

1. By Assumption 1, changes in the club's payoff from having a reformed new member at time 1, Π^R, does not affect any of the threshold values.

[2] Since $p(N)$ is a strictly decreasing function such that $p(N) \in (0, 1)\ \forall N$, it cannot be globally concave.

2. If the club's immediate payoff from accepting a fully reformed applicant early, Π^I, increases, then all threshold values increase as well. This means that the club's policy shifts towards early entry offers (which is straightforward.)

3. As regards the applicant's membership benefit π, in case A $\partial d_2^{EG}/\partial\pi = 0$ and $\partial d_2^{RL}/\partial\pi = -n_1(\partial\Delta/\partial\pi)/(n_2\alpha)$, and in case B $\partial d_2^{EG}/\partial\pi = -\delta/(\alpha-1)$ and $\partial d_2^{RL}/\partial\pi = -\delta/(\alpha-1) - n_1(\partial\Delta/\partial\pi)/(n_2(\alpha-1))$. Here

$$\frac{\partial\Delta}{\partial\pi} = \begin{cases} -\delta < 0, & \delta(\pi - q_R c N_1) \le d_1 \le \delta(\pi - q_L c N_1), \\ 0, & \text{otherwise,} \end{cases}$$

i.e., in most cases $\partial\Delta/\partial\pi = 0$, and $\partial\Delta/\partial\pi < 0$ iff postponing the accession of a wave 2 applicant relaxes the IC constraint of a wave 1 applicant. In case A, the IC constraint of a late entrant (3) is not binding ($r^L = 0$) so that $\partial d_2^{EG}/\partial\pi = 0$ and $\partial d_2^{RL}/\partial\pi \ge 0$, i.e., the club's policy either (in most cases) stays the same or shifts towards early entry offers.

In case B, the IC constraint (3) is binding ($r^L > 0$) and relaxes if π increases so that late entry offers become less expensive. This results in $\partial d_2^{EG}/\partial\pi \le 0$ and, in most cases, $\partial d_2^{RL}/\partial\pi \le 0$, which means that the club's policy shifts towards late entry offers. If $\partial\Delta/\partial\pi < 0$ as well, i.e., if an increase in π relaxes the IC constraints of both waves as the club switches from "gradualism-2" to "late big bang," then $\partial d_2^{RL}/\partial\pi$ has the same sign as $n_1 - n_2$, so that the club's policy may shift towards early entry for a wave as the membership benefit increases when the other wave is larger.

4. All threshold values decrease in α as an increase in α means that the "net transfers" to early entrants increase whereas the "net transfers" to late entrants remain unchanged. Thus, the club's policy shifts towards late entry offers.

5. An increase in the discount rate δ increases the discounted expected congestion costs at time 1, thus shifting the club's policy towards early entry offers.

6. As regards the congestion cost parameter c, the primary effect of an increase in c is the increase in expected congestion costs. Moreover, the IC constraint (3) is also reinforced, and

$$\frac{\partial\Delta}{\partial c} = \begin{cases} 0, & d_1 \le \delta(\pi - q_R c N_1), \\ \delta q_R N_1 > 0, & \delta(\pi - q_R c N_1) \le d_1 \le \delta(\pi - q_L c N_1), \\ \delta(q_R - q_L)N_1 > 0, & d_1 \ge \delta(\pi - q_L c N_1) \end{cases}$$

is nonnegative. Thus, in case A, where no other effect is present, both d_2^{EG} and d_2^{RL} decrease in c and the club's policy shifts towards late entry offers. In case B there appears a secondary effect due to the reinforcement of the IC constraint so that $\partial d_2^{EG}/\partial c$ has the same sign as $q_G n_2 - (q_E - q_G)n_0$, which can be shown to be positive, and $\partial d_2^{RL}/\partial c$ has the same sign as $(\delta q_L n_2 - \delta(q_R - q_L)n_0)N_1 - n_1\partial\Delta/\partial c$, which is ambiguous.

7. The effect of the size parameters n_0, n_1 and n_2 cannot be easily characterised without additional assumptions about the probability of internal reform failure $q = q(N_0)$ as a function of the club's size at time 0.

3.4 Admittance order

One of the findings of Burkart and Wallner (2000) was that the club might follow *reversed admittance order*, i.e., it might be possible that more advanced applicants are admitted late whereas less advanced ones are admitted early. In their model it was too costly for the club to pay incentive compatible transfers to less advanced applicants in the case of a late entry offer, and the club was willing to extract the maximal possible entrance fee from the applicants. Kúnin (2000) showed that if the club receives an immediate payoff from accepting an applicant early, and if this payoff decreases in the applicant's reform distance faster than this distance itself, then reversed admittance order is impossible.

In this framework, reversed admittance order occurs if either wave 1 is the more advanced ($d_1 < d_2$) but the club uses a "gradualism-2" strategy (call it RAO-2), or wave 2 is the more advanced ($d_2 < d_1$) but the club uses a "gradualism-1" strategy (call it RAO-1.) Consider the case of RAO-1 (RAO-2 is analogous). As is shown above, the club uses a "gradualism-1" strategy iff $d_2 > d_2^{EG}$ and $d_1 \leq d_1^{GL}(d_2)$. Thus, RAO-1 occurs iff

$$d_2^{EG} < d_2 < d_1 \leq d_1^{GL}(d_2),$$

whence the following criterion can be derived.

Lemma 2 *RAO-1 can occur iff there exists a value d such that*

$$d_2^{EG} < d \leq d_1^{GL}(d). \tag{13}$$

Therefore, the condition that $d_2^{EG} < d_1^{GL}$, where d_1^{GL} is evaluated at $\bar{\Delta} = 0$, is a necessary condition for RAO-1.

If the two waves are equal in size ($n_1 = n_2$), then $q_G = q_R$ and $d_1^{GL}(d) \equiv d_2^{RL}(d)$ so that the following can be concluded from Lemma 1.

Corollary 3 *Under Assumptions 1 to 3 reversed admittance order is impossible if the waves are equal in size.*

A question of practical importance is whether it might be possible that the club's optimal strategy is to make an early entry offer to a less advanced but *small* group of applicants and to make a late entry offer to a more advanced but *large* group. The answer is given by the following proposition.

Proposition 3 *Let Assumptions 1 to 3 hold. Then reversed admittance order is impossible regardless of the size of the waves.*

The proof of this proposition can be found in Appendix B. The club either follows direct admittance order by giving an early entry offer to a more advanced wave, or uses a "big bang" approach.

Again, this result crucially depends on Assumption 2 and $\alpha > 1$. If Assumption 2 does not hold and the club's choice of admittance strategies corresponds to Figure 4, then RAO can occur unless $n_1 = n_2$, and if $n_1 = n_2$, then the club may prefer accepting either of two waves equal in both size and reform status early and accepting the other one late rather than accepting both waves at the same time.

4 No entry offers

In the model as it is introduced in Section 2, the club has only two options for each applicant: an early entry offer of a late entry offer, and Assumption 1 implies that the club cannot reject an applicant completely. This means that as the applicant's reform distance grows, the minimal transfers to such an applicant also grow unlimitedly. Thus, Assumption 1 is implausible for large values of d.

Consider the following modification of the framework. Let the club be allowed to reject an applicant, i.e., to make no entry offer.[3] Thus, the club has three options regarding each wave of applicants: early, late, and no offer. This yields a total of nine classes of strategies.

In addition, since it is not known *a priori* whether the internal reform succeeds or fails, it may happen that it is profitable for the club to make a late entry offer *ex ante* but it is not profitable to accept the applicant *ex post* due to congestion when the internal reform fails. In other words, the issue of club commitment becomes relevant. For simplicity, I assume that the following assumption holds.

Assumption 4 (Commitment) *Whether or not the club's internal reform succeeds, the club making a late entry offer commits to admit the applicant, provided that the applicant has met the club's standards.*

Let the club's payoff associated with a rejected applicant equal zero. The club's payoffs for the four strategy classes involving either early or late entry of both waves are given in Section 3. If the club decides to accept wave i *early* and reject the other wave, then its payoff equals

$$W_{Ei} = n_i\Big(\delta\Pi^R - d_i + \Pi^I - \alpha d_i\Big) - \delta q(n_0 + n_i)C(n_0 + n_i).$$

Note that the club size after enlargement is no longer $n_0 + n_1 + n_2$. If the club decides to accept wave i *late* and reject the other wave, then its payoff equals

$$W_{Li} = n_i\Big(\delta\Pi^R - d_i - \delta r_i^L\Big) - \delta q_L C(n_0 + n_i).$$

In this equation, the probability of the internal reform failure equals $q_L = q(n_0)$ since the only wave accepted is admitted late. Finally, the club's payoff from a "no enlargement"

[3] This option is present in both Burkart and Wallner (2000) and Kúnin (2000).

strategy, when neither wave is admitted, equals

$$W_N = -\delta q_L C n_0.$$

Then the club prefers "late big bang" to admitting wave i late and rejecting the other wave j iff

$$\delta \Pi^R \geq d_j + \delta r_j^L + \delta q_L C, \tag{14}$$

i.e., iff the benefits per applicant simply exceed total transfers plus congestion costs per applicant (this holds because the probability of the internal reform failure remains unchanged). Under the same condition (14), the club prefers admitting wave j late and rejecting the other wave to the "no enlargement" approach.

Analogically, the club prefers "gradualism-i" to accepting wave i alone early while making no entry offer to wave j iff

$$\delta \Pi^R \geq d_j + \delta r_j^L + \delta q_X C, \tag{15}$$

where $X = G$ for $j = 2$ and $X = R$ for $j = 1$. Again, the probability of internal reform failure remains unchanged so that the club offers late entry rather than no entry to the other wave iff benefits exceed total transfers plus congestion costs. The thresholds implied by (15) are lower than those implied by (14) as $q_X > q_L$ (both these inequalities have the form $\delta \Pi^R \geq F(d, q)$, where $F(d, q) = d + \delta r^L(d, q) + \delta q C$ is strictly increasing in both d and q).

The club prefers accepting wave i alone early to accepting this wave alone late iff

$$n_i \left(\Pi^I - \alpha d_i + \delta r_i^L \right) \geq \delta (q_X - q_L) C (n_0 + n_i), \tag{16}$$

where $X = G$ for $i = 1$ and $X = R$ for $i = 2$. A comparison of (16) and (8) shows that the right-hand side is lower in (16), and that there is no negative term on the left-hand side of (16). Hence, the threshold implied by (16) is higher than d_1^{GL} (if $i = 1$) or d_2^{RL} (if $i = 2$).

Finally, it is possible to show that the boundary between "late big bang" and accepting one wave early is an increasing function in the (d_1, d_2)-plane. This means that it is possible that the club prefers "late big bang" for some (d_1, d_2), and as one of the reform distances grows, the club switches to accepting the more advanced wave *early* and rejecting the less advanced wave completely. This can be explained by the fact that the overall congestion costs in the case of the internal reform failure decrease when one of the waves gets rejected, which compensates for the increase in the probability of the internal reform failure associated with accepting the other wave early.

The arrangement of all nine strategies is shown in Figure 5. The labels "Ei" and "Li" denote the sets of parameters for which the club accepts wave i early or late, and rejects the other wave. The label "N" denotes the set of parameters wherein the club rejects both waves. In this figure, it is implicitly assumed that the club's benefit from having a reformed new member at time 1, Π^R is sufficiently high for the threshold values involving no entry offers to be higher than the threshold values not involving such offers.

5 Conclusion

This paper combines club theory, incomplete contracts, and transition economics approaches to the problem of club enlargement. In the club theory approach, an increase in the club size results in two effects, the positive membership effect and the negative congestion effect (Cornes and Sandler, 1986). In the incomplete contract approach of Burkart and Wallner (2000), the club strategically chooses the dates of admittance depending on the initial characteristics of the applicants. In the transition economics approach, the admission of each wave is treated as a reform in a broader sense along with the internal reform. Thus, the problem of enlargement strategy can be interpreted as the problem of optimal sequencing of reforms (Roland, 2000).

In this paper, I have investigated how a club facing two waves of applicants and the need for internal reform uses its monopoly power over incorporating new members in order to choose its optimal enlargement strategy. Under quite general assumptions, the club prefers a "gradualism" approach when the waves are heterogeneous in their initial compliance with the club's standards. In addition, the club never uses "reversed admittance order," i.e., the club never admits the more advanced wave of applicants after the less advanced wave of applicants.

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APPENDIX

A Proof of Lemma 1

It is sufficient to show that the first part of the claim of the Lemma is true when $\Delta = 0$ in (9) and (10) because d_2^{RL} decreases in Δ. Four cases are possible according to the signs of $A^{EG} = d_2^{EG} - \delta(\pi - q_G cN_1)$ and $A^{RL} = d_2^{RL} - \delta(\pi - q_L cN_1)$, where $d_2^{RL} \geq d_2^{RL}(d_1)$ is obtained by substituting $\Delta = 0$ into (9) and (10).

If $A^{EG} \leq 0$ and $A^{RL} \leq 0$, then d_2^{EG} is determined by (6) and d_2^{RL} is determined by (9). The denominators are identical and positive, and the numerators differ in the multiplier at $\delta CN_1 > 0$: the multiplier equals $-(q_E - q_G)$ in (6) and $-(q_R - q_L)$, which is less than $-(q_E - q_G)$ by Assumption 2, in (9). Thus, the numerator in (6) is greater than the numerator in (9), which implies $d_2^{EG} > d_2^{RL}$.

If $A^{EG} > 0$ and $A^{RL} > 0$, then d_2^{EG} is determined by (7) and d_2^{RL} is determined by (10). Again, the denominators are identical and positive (as $\alpha > 1$), and there are two differences in the numerators. First, the multiplier at δCN_1 is smaller in (10) as in the previous case. Second, the multiplier at $n_2 \delta cN_1 > 0$ equals q_G in (7) and $q_L = q(n_0) < q(n_0 + n_1) = q_G$ in (10), so that $d_2^{EG} > d_2^{RL}$.

If $A^{EG} > 0$ and $A^{RL} \leq 0$, then d_2^{EG} is determined by (7) and d_2^{RL} is determined by (9). Since $A^{EG} > 0$, i.e., $d_2^{EG} > \delta(\pi - q_G cN_1)$, from (7) it follows that

$$X^{EG} = n_2\Big(\Pi^I - \alpha\delta(\pi - q_G cN_1)\Big)/(\delta CN_1) > q_E - q_G. \tag{17}$$

If $d_2^{EG} \leq d_2^{RL}$, then from (7) and (9) it follows that

$$\alpha(q_E - q_G) - (\alpha - 1)(q_R - q_L) \geq X^{EG}. \tag{18}$$

Adding (17) and (18) yields

$$(\alpha - 1)(q_E - q_G) > (\alpha - 1)(q_R - q_L).$$

Since $\alpha > 1$, this is equivalent to $q_E - q_G > q_R - q_L$, which contradicts to Assumption 2.

If $A^{EG} \leq 0$ and $A^{RL} > 0$, then d_2^{EG} is determined by (6) and d_2^{RL} is determined by (10). Since $A^{EG} \leq 0$, i.e., $d_2^{EG} \leq \delta(\pi - q_G cN_1)$, from (6) it follows that $X^{EG} \leq q_E - q_G$, where X^{EG} is defined in (17). Since $A^{RL} > 0$, i.e., $d_2^{RL} > \delta(\pi - q_L cN_1)$, from (10) it follows that $X^{RL} > q_R - q_L$, where

$$X^{RL} = n_2\Big(\Pi^I - \alpha\delta(\pi - q_L cN_1)\Big)/(\delta CN_1).$$

Thus, $X^{RL} > q_R - q_L > q_E - q_G \geq X^{EG}$, i.e., $X^{RL} > X^{EG}$. However,

$$X^{RL} - X^{EG} = n_2 \alpha \delta c N_1 (q_L - q_G)/(\delta C N_1) < 0,$$

which is a contradiction, proving that this case is impossible.

Thus, in all cases $d_2^{EG} > d_2^{RL} \geq d_2^{RL}(d_1)$. The proof of the second part of the claim is analogous.

B Proof of Proposition 3

It is sufficient to show that RAO-1 is impossible, i.e., that (13) cannot hold. Then RAO-2 is impossible by analogy.

Consider Assumption 2. Since $q(N)$ is concave,

$$\forall x, y, \forall \beta \in (0,1) \; q(\beta x + (1-\beta) y) > \beta q(x) + (1-\beta) q(y). \tag{19}$$

Let $x = n_0 + n_1 + n_2$, $y = n_0$ and $\beta = n_1/(n_1 + n_2)$. Then from (19) it follows that

$$\frac{q_G - q_L}{n_1} > \frac{q_E - q_G}{n_2}. \tag{20}$$

Let RAO-1 be possible. Then by Lemma 2 $d_2^{EG} < d_1^{GL}$, where d_1^{GL} is evaluated at $\bar{\Delta} = 0$. Four cases are possible according to the signs of $A^{EG} = d_2^{EG} - \delta(\pi - q_G c N_1)$ and $A^{GL} = d_1^{GL}(d_2) - \delta(\pi - q_L c N_1)$.

If $A^{EG} \leq 0$ and $A^{GL} \leq 0$, then $d_2^{EG} < d_1^{GL}$ is equivalent to

$$\frac{q_G - q_L}{n_1} < \frac{q_E - q_G}{n_2}, \tag{21}$$

which directly contradicts (20).

If $A^{EG} > 0$ and $A^{GL} > 0$, then $d_2^{EG} < d_1^{GL}$ is equivalent to

$$\frac{(q_G - q_L)c}{C} + \frac{q_G - q_L}{n_1} < \frac{q_E - q_G}{n_2},$$

which also contradicts (20) since $q_G > q_L$.

If $A^{EG} > 0$, $A^{GL} \leq 0$, and RAO-1 is possible, then by Lemma 2 $\exists d$: $d_2^{EG} < d \leq d_1^{GL}(d)$. Since $A^{EG} > 0$, $d_2^{EG} > \delta(\pi - q_G c N_1)$, which is also equivalent to

$$\frac{\Pi^I - \alpha\delta(\pi - q_G c N_1)}{\delta C N_1} > \frac{q_E - q_G}{n_2}. \tag{22}$$

Since $A^{GL} \leq 0$, $d_1^{GL}(d) \leq \delta(\pi - q_L c N_1)$. Thus, $\delta(\pi - q_G c N_1) < d \leq \delta(\pi - q_L c N_1)$ so that

$$\bar{\Delta} = d - \delta(\pi - q_G c N_1)$$

and

$$d_1^{GL}(d) = \frac{n_1\Pi^I - \delta(q_G - q_L)CN_1 - n_2\bar{\Delta}}{n_1\alpha} = \frac{n_1\Pi^I - \delta(q_G - q_L)CN_1 - n_2(d - \delta(\pi - q_G cN_1))}{n_1\alpha}.$$

Then $d \leq d_1^{GL}(d)$ is equivalent to

$$d \leq \frac{n_1\Pi^I - \delta(q_G - q_L)CN_1 + \delta n_2(\pi - q_G cN_1)}{n_1\alpha + n_2}, \tag{23}$$

whereas $d_2^{EG} < d$ means that

$$\frac{n_2\Big(\Pi^I - \delta(\pi - q_G cN_1)\Big) - \delta(q_E - q_G)CN_1}{n_2(\alpha - 1)} < d. \tag{24}$$

Adding (23) and (24) yields

$$\frac{\Pi^I - \alpha\delta(\pi - q_G cN_1)}{\delta CN_1}(n_1 + n_2) < \frac{q_E - q_G}{n_2}(n_1\alpha + n_2) - (\alpha - 1)(q_G - q_L). \tag{25}$$

From (22) and (25) it follows that

$$\frac{q_E - q_G}{n_2}(n_1 + n_2) < \frac{q_E - q_G}{n_2}(n_1\alpha + n_2) - (\alpha - 1)(q_G - q_L),$$

which is equivalent to (21), which is a contradiction.

The last possible case is when $A^{EG} \leq 0$ and $A^{GL} > 0$. The first inequality is equivalent to

$$\frac{\Pi^I - \alpha\delta(\pi - q_G cN_1)}{\delta CN_1} \leq \frac{q_E - q_G}{n_2}, \tag{26}$$

and the second one leads to

$$\frac{q_G - q_L}{n_1} < \frac{\Pi^I - \alpha\delta(\pi - q_L cN_1)}{\delta CN_1}. \tag{27}$$

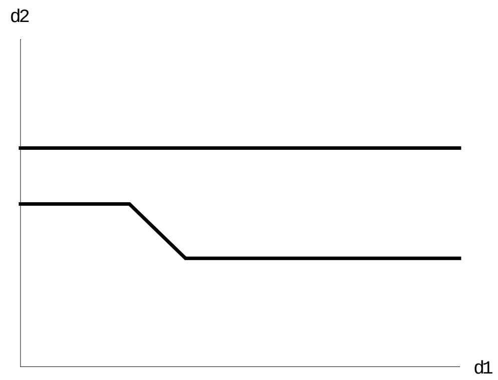
From (20), (26) and (27) it follows that

$$\Pi^I - \alpha\delta(\pi - q_G cN_1) < \Pi^I - \alpha\delta(\pi - q_L cN_1),$$

i.e., that $q_G < q_L$, which contradicts the fact that $q_G > q_L$. Thus, this case cannot occur, which completes the proof.

FIGURES

1



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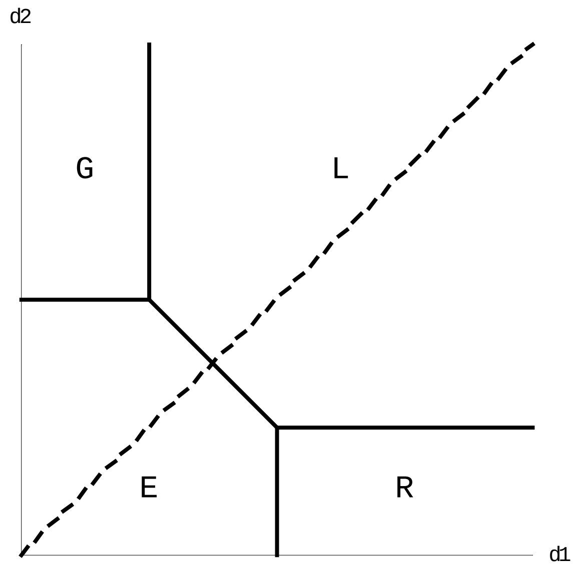

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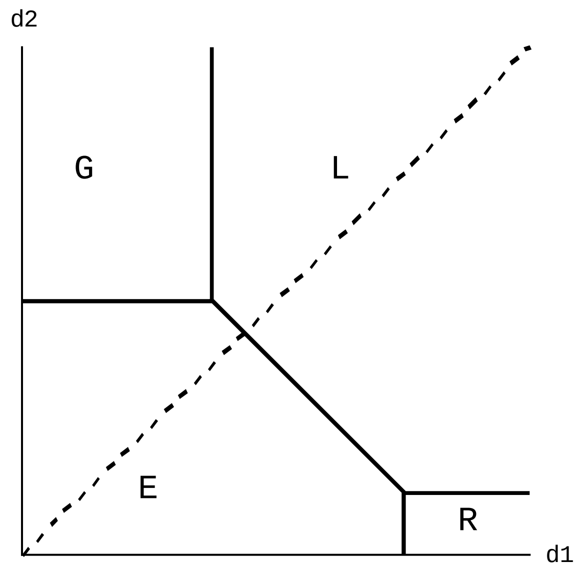

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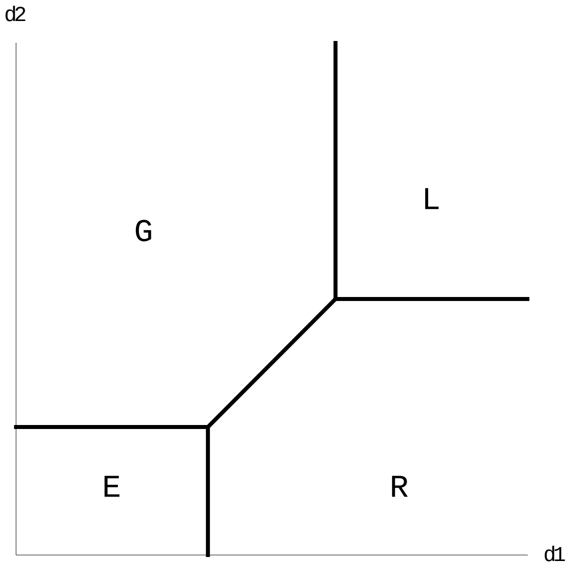

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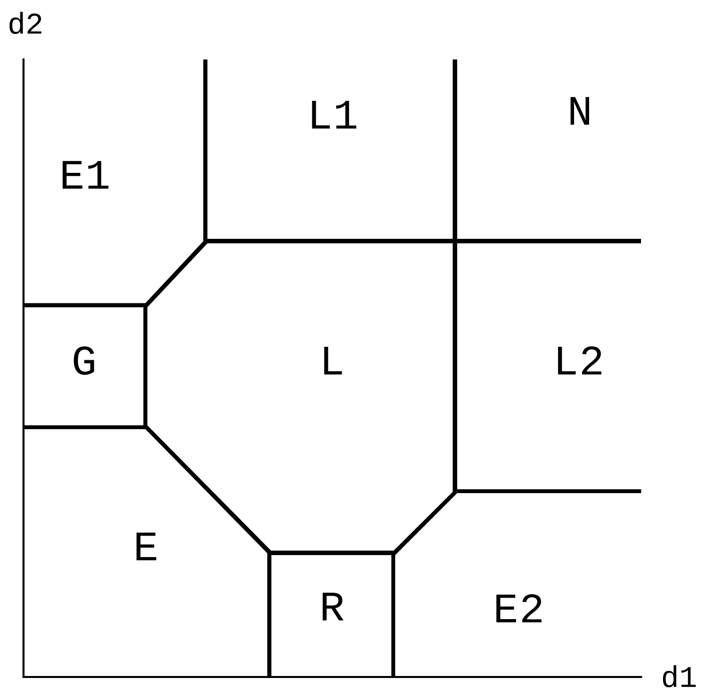

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