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Ongoing quest for QWERTY

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Abstract

First, we replicate the remarkable result of Hossain & Morgan (AER 2009), in which subjects in an experimental market tip almost perfectly to the superior platform even if an inferior platform enjoys initial monopoly. Next, we show that this result disappear when seemingly innocent increases in out-of-equilibrium payoffs are introduced. The inflated payoffs do not alter payoff- or risk-dominance relations, and does not impact on players' security levels. We conclude that the need for a theory of equilibrium selection cannot be bypassed by appealing to the realities of the (experimental) market place.

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Introduction

In a recent laboratory experiment Hossain & Morgan (2009) - hereafter HM - find that the Pareto dominant equilibrium always prevails in a coordination game. This strong coordination result suggests that markets manage to coordinate on the superior technology platform. However, the coordination result is fragile. We find that it breaks down when an innocent change in the out-of-equilibrium payoffs of HMs experiment is introduced. If anything, this change should make coordination on the superior platform more likely according to standard theory.

One might expect the market to tip to one technology platform when two ore more platforms compete for market shares in the presence of network effects. Network effects arise when a user has more utility from a good when other users have the same good. In situations with a superior and an inferior platform users face a coordination problem; it is better for all to be on the superior platform but such coordination requires mutually consistent beliefs and actions. Mutual consistency can not be taken for granted in the absence of pre play communication, and perhaps not even in its presence. In such situations central questions are whether the market equilibrium tips to the inferior or the superior platform and whether the equilibrium outcome is influenced by a platform enjoying a head start.

The QWERTY-phenomena presented by David (1985) is a famous example of a market tipping to the inferior platform. David argues that we are stuck in a bad equilibrium with the QWERTY arrangement on keyboards even though more efficient arrangements like Dvorak exist.

A current example is the choice of car technology; should I go for a fossil fuel based platform or a new environmental friendly platform, such as an electricity or hydrogen based one? The network of services (e.g. filling/charging stations, repair shops and second-hand market) is important for consumers. At the same time the extent of this network depends on the number of consumers that use the technology. The possibility of being in a small network may prevent the adoption of that technology, even if a widespread change of technology is preferred.

Several papers are critical to the QWERTY phenomena. First, Liebowitz & Margolis (1990 and 1995) question whether the Dvorak keyboard design is really more efficient. Moreover, they point out that a firm with a new superior platform has an incentive to sponsor the switch to the new platform. Second, Tellis, Niraj & Yin (2009) analyze several high-tech markets with potential network effects, and find that the highest quality products always end up dominating the market. Finally, HM conclude from experimental data that the danger of QWERTY type outcomes in the market "lies more in the minds of the theorists than in the reality of the marketplace".

We test the robustness of HMs remarkable results: (i) markets always coordinate on the superior platform and (ii) a first mover advantage to the inferior platform does not influence the coordination on the superior platform. First we replicate HMs laboratory results. Then we make our innocent change in the payoffs of HMs experiment. The change does not alter the payoff matrix in any way that, according to standard theory, should wipe out coordination on the superior platform. However, coordination on the superior platform is wiped out.

No accepted theory of equilibrium selection exist. The most influential contribution is due to Harsanyi & Selten (1988). Their theory says that if one particular equilibrium is Pareto dominant as well as risk dominant it ought to be selected. However, their theory has a firm micro foundation only for 2×2 games. For n-person games with finite strategy sets, several competing definitions of risk dominance exist (Carlsson & Van Damme 1993).

Equilibrium selection represents the, perhaps, most fundamental unresolved issue in game theory. Our results cast doubt on HMs notion that experiments can bypass this issue by appeal to "the reality of the marketplace". Experimentation may, however, indicate *what* a theory of equilibrium selection must address. Our results demonstrate that equilibrium selection is not empirically trivial in the HM format, but is crucially, and somewhat strangely, influenced by out-of-equilibrium payoffs.

Design

Our experiment consists of six sessions. A session consists of three consecutive sets, and each set consists of 15 periods. In the first 5 periods of a set subjects are constrained to choose a monopoly platform ("the incumbent"). In the last 10 periods of a set subjects are free to choose between the incumbent and an alternative platform ("the entrant"). Thus a session has a total of 45 periods. Unique subjects were used in different sessions, and markets of four subjects were randomly formed at the beginning of each set from a total of either 16 or 20 subjects. The probability of identical markets forming in different sets of a session was marginal.

At the start of a session subjects were randomly assigned a type from a binary type set. Types were kept throughout the session. There were two pairs of opposite types in each market.

The matrices and the incumbents were varied systematically over the sets in a session. We utilized four matrixes (Table 1). In the matrices numbers in the cells of columns 3 and 5 are payoffs from choosing platform A, while numbers in the cells of columns 4 and 6 are payoffs from choosing platform B. Access fees of the respective platforms are provided for each matrix. Matrices 1* and 2* differ from matrices 1 and 2 only by the inflated out-of-equilibrium payoff in square brackets. The inflated payoffs are inspired by a related work due to Hossain *et al.* (2011)

Table 1: *Payoff matrices*

Matrices 1 [1*]		Number of players of the same type as chooser (including herself)	
		1	2
Number of players of	0	3, 6	3, 6
opposite type of	1	9,10	6, 7
chooser	2	12, 13 [24]	11, 12
		Access fees: (2,5)	

Matrices 2 [2*]		Number of players of the same type as chooser (including herself)	
		1	2
Number of players of	0	4, 4	4, 4
opposite type of	1	8, 11	6, 8
chooser	2	11 [22], 13	10, 12
		Access fees: (2,3)	

In each of the four matrices there are three equilibria in pure strategies: i) all four players choose platform A, ii) all four players choose platform B, and iii) pairs of opposite player-types choose opposite platforms. Matrices 1 and 2 are identical to the ones used in HM. We refer to the equilibria in i) and ii) as "tipping", while the equilibrium in iii) is referred to as "non-tipping".

In matrices 1 and 1* tipping on platform A (the cheap platform) Pareto dominates (is superior to) the other pure strategy equilibria. Furthermore, the superior equilibrium also risk dominates the other pure strategy equilibria.[1]

In matrices 2 and 2* tipping on platform B (the expensive platform) is superior to the other pure strategy equilibria. Furthermore, the superior equilibrium risk dominates the non-tipping equilibrium, while it has the same Nash product in deviation losses as the equilibrium tipping on platform A (so this relation is therefore neutral in risk dominance terms).

Inflating the out-of-equilibrium payoffs in matrices 1* and 2* does not impact on the payoff- or risk dominance relations between pure strategy equilibria in the four matrices. The security levels (i.e. maximin) of the players are also unaffected by the inflation; it is 1 for both platform choices in matrices 1 and 1*, and 2 for platform A in matrices 2 and 2*.

There is also an equilibrium in mixed strategies in each of the four matrices. In this equilibrium all players randomize with identical distributions over platforms A and B. In going from matrix 1 (2) to matrix 1* (2*), the probability weight on platform A (B) in the mixed strategy equilibrium is increased. Thus, our inflated out-of-equilibrium payoffs make coordination on the superior plat-

[1] As mentioned, several competing definitions of risk dominance exist for n-person games with finite strategy sets. We use the definition suggested by Güth (1992) throughout. It is a straight foreward extension of the main ideas in Harsanyi & Selten (1988), and Güth provides and axiomatic foundation for his extension.

form more likely, *given* that the mixed strategy equilibrium is being played.[2] The mixed strategy equilibrium is payoff dominated by all pure strategy equilibria in the original matrices (1 and 2). In the inflated matrixes (1* and 2*) the two tipping equilibria continues to payoff dominate the mixed strategy equilibrium. However, for one pair of opposite players (but not for the other pair) the mixed strategy equilibrium payoff-dominates the non-tipping equilibrium in the inflated matrices.[3] This should, if anything, make play of the mixed strategy equilibrium more attractive in the inflated matrices.

To sum up: from standard theory one would expect players facing the inflated matrices to coordinate no less on superior platforms than players facing the original matrixes.

The six sessions of our experiment are described in Table 2. Sessions I, II and III replicated HM, while sessions I*, II* and III* extends HM.

Table 2: *Sessions* (Matrix; Incumbent)

	Set 1	Set 2	Set 3	N	Date
Session I	(1; B)	(2; A)	(1; B)	16	9. November 2011
Session I*	(1*; B)	(2*; A)	(1*; B)	20	9. November 2011
Session II	(2; A)	(1; B)	(2; A)	16	24. January 2012
Session II*	(2*; A)	(1*; B)	(2*; A)	20	25. January 2012
Session III	(1; A)	(2; A)	(1; A)	16	10. November 2011
Session III*	(1*; A)	(2*; A)	(1*; A)	20	10. November 2011

As can be seen, in sessions I and I* the incumbent is always inferior; this is also the case in sessions II and II* (which simply runs I and I* in reversed order); while in sessions III and III* the incumbent is always cheap.

To facilitate replication, the original z-tree program files and the original instructions from HM was used in sessions I, II and III. Files and instructions were modified only to: i) account for the changed matrices in sessions I*, II* and III*, and ii) account for the new exchange rate of experimental points (from points to Norwegian Kroner (NOK) rather than to Hong Kong Dollars).

A total of 108 subjects were recruited by e-mail from the pool of BA students at BI Norwegian Business School. Subjects were used for a maximum of 90 minutes at expected earnings of approximately 200 NOK. Actual sessions lasted on average 75 minutes, with average earnings of 196 NOK (which is slightly above the hourly rate for research assistants at the institution). At the end of the experiment points earned were converted at a rate of 0.6 NOK per point. Subjects were paid their earnings privately in NOK on exit.

All sessions were executed in the research lab of BI Norwegian Business School. On arrival subjects drew a ticket with a number corresponding to their

[2] The probability of player i chosing (the superior) platform A is 0.374 in matrix 1, and 0.491 in matrix 1*. The probability of player i chosing (the inferior) platform A is 0.561 in matrix 2, and 0.458 in matrix 2*.

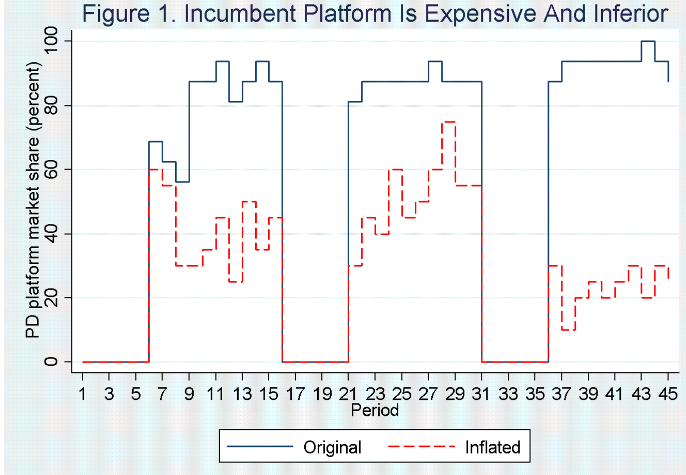
[3] The expected gain (net of access fees) from playing the mixed stratey equilibrium for player i is 4.49 (5.45) in matrix 1 (2), and 5.31 (6.15) in matrix 1* (2*).

cubicle in the lab (in order to break up social groups). Once seated, instructions were read aloud to achieve public knowledge about the rules of the game, payoffs, and exchange rates. Subsequently, the session was conducted with a strict no communication rule enforced. All interactions were conducted through the PC network and anonymity was preserved throughout the experiment.

Results

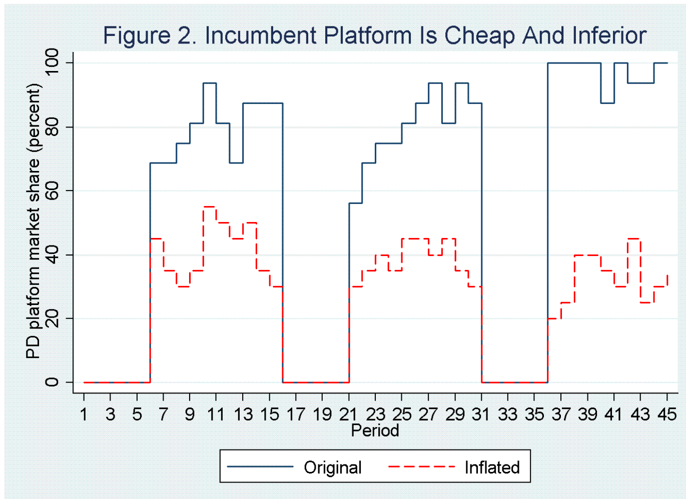
Figure 1 show results from three sets in which the incumbent is expensive and inferior (set 1 and 3: session I/I*; set 2: session II/II*). The y-axis measures the average percentage of subjects choosing the superior platform (i.e. the market share of the superior platform). The solid line use the original matrix from HM, while the stapled line use the matrix with inflated out-of-equilibrium payoff.

Figure 1. Incumbent Platform Is Expensive And Inferior



The solid line in Figure 1 corresponds to Figure 1 in HM. The main result from HM is reproduced. After some initial problems, markets coordinate on the superior platform. The coordination is not perfect, but after period 8 the market share of the superior platform stays above 80 percent (excluding the monopoly phases where the inferior platform was the only choice). However, the result changes dramatically when the inflated payoff is introduced. The dotted line shows that the markets do not coordinate on the superior platform in this case. In fact, the market share of the superior platform is less than 30 percent for the last 10 periods. This is certainly surprising since there is no clear mechanism by which the inflated out-of-equilibrium payoffs should influence equilibrium selection.

Figure 2 show results from three sets in which the incumbent is cheap and inferior (set 1 and 3: session II/II*; set 2: session III/III*). As before the market share of the superior platform is measured on the y-axis. The solid line use the original matrix from HM, while the stapled line use the matrix with inflated out-of-equilibrium payoff.



The solid line in Figure 2 corresponds to Figure 2 in HM. Again, the main result from HM is reproduced, while coordination on the superior platform breaks down when the inflated payoff is introduced.

Taken together, Figures 1 and 2 show that HM's result on coordination is fragile. A seemingly innocent change to the out-of-equilibrium payoff destroy market coordination on the superior platform. Thus, the incumbent platform may retain market shares even if the entrant platform is superior.

Table 3 displays average market share for the superior platform per market in set 3 ("share"), and the average share of markets that were coordinated on the superior platform in set 3 ("coord"). The monopoly phase (periods 31-35) was excluded prior to calculating averages. Data are broken down on sessions and on original versus inflated payoffs. We use these data to perform Mann-Whitney U-tests (two sample ranksum tests). Markets are selected as observational units since strategic interactions takes place within, but presumably (given our matching protocol and information partition) not across markets. Thus market level data should be independent. The final set is selected based on the assumption that behavior has had time to settle down.

Table 3: *Set 3, per market data*

	Session I		Session II		Session III	
Market	share	coord	share	coord	share	coord
1	0.975	.900	1.000	1.000	.975	.900
2	0.825	.300	1.000	1.000	1.000	1.000
3	0.975	.900	0.900	0.700	1.000	1.000
4	0.950	.800	1.000	1.000	1.000	1.000

	Session I*		Session II*		Session III*	
Market	share	coord	share	coord	share	coord
1	0.400	0.000	0.100	0.000	0.775	0.300
2	0.175	0.000	0.100	0.000	0.525	0.200
3	0.150	0.000	0.700	0.200	0.400	0.000
4	0.400	0.000	0.150	0.000	0.525	0.200
5	0.050	0.000	0.575	0.000	0.325	0.000

First, we test the differences in the market shares of the superior platform between the original and the inflated treatments. The distributions in the two treatments differ significantly in all sessions (Session I vs I* $p = 0.0135$; Session II vs II* $p = 0.0123$; Session III vs III* $p = 0.0123$).[4] So far we have discussed market shares of the superior platform as a measure of coordination. Alternatively we may look at the average share of markets that were coordinated. From Table 3 we see that coordination on the superior platform rarely occurs in the inflated treatments. In fact, there were no instances of such coordination at all in Session I*.

Second, we test whether costs of the platforms matters for the market share of the superior platform. In Sessions I and I* the incumbent platform is expensive and inferior, while in Sessions II and II* the incumbent platform is cheap and inferior. We test the differences of distributions in Session I vs II and in Session I* vs II*. In both cases there are no significant differences (Session I vs II $p = 0.1367$; Session I* vs II* $p = 0.8330$). Hence, we find support for the same result on costs as HM; costs of the platforms do not seem to matter for coordination.

Third, we investigate whether the inferiority or superiority of the incumbent matters for the market share of the superior platform. In Sessions I and I* the incumbent platform is expensive and inferior while in Sessions III and III* the incumbent platform is cheap and superior. We test the differences in distributions in Session I vs III and in Session I* vs III*. In both cases there are significant differences (Session I vs III $p = 0.0336$; Session I* vs III* $p = 0.0439$). Since the incumbent platform is different in Sessions I and III across both the cost and the Pareto dimension, we cannot directly conclude on what drives these differences. However, above we established that costs do not seem

[4] We also find significant differences between the original and inflated treatments for sets 1 and 2.

to matter. Further, from Table 3 we see that the market share for the superior platform is larger in Sessions III and III* than in Sessions I and I*. Thus, our test indicates that coordination on the superior platform occurs less frequently when the inferior platform enjoys a first-mover advantage.

Conclusion

The QWERTY hypothesis is that markets can lock in to a bad equilibrium if an inferior platform is privileged by an initial monopoly. HMs experiment seem to disprove this hypothesis. They find that markets always coordinate on superior platforms, and that such coordination is not inhibited by the presence of inferior incumbents.

We demonstrate that their findings are crucially conditioned on the choice of payoff matrices. Inflating out-of-equilibrium payoffs in ways that, if anything, ought to facilitate coordination on superior platforms, destroy the results of HM.

It is worth noting that our inflation of payoffs does not alter the security levels of players. Thus, our negative result can not be driven by a trade-off between payoff dominance and (out-of-equilibrium) security levels, as seems to be the case in Van Huyk et al. (1991).

Since payoff- and risk dominance relationships between equilibria in pure strategies remain unaltered by the inflation of payoffs, the seminal equilibrium selection theory of Harsanyi & Selten (1988) and Güth (1992) does not come in to play either.

We are not able to provide a sensible economic interpretation of our inflated matrices compared to the original matrices of HM. In our view neither the original nor the inflated matrices provide some "best representation" of "the realities of the marketplace". For this reason we believe our negative result should be taken seriously.

This means acknowledging that we are back at square one: we do not understand equilibrium selection in general, nor - by implication - do we understand coordination on superior technologies in the presence of network externalities.

Ending on a more positive key; our results indicate that the theory of equilibrium selection would prosper from paying closer attention to the role of out-of-equilibrium payoffs, even when such payoffs are unrelated to risk dominance and security levels.

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