STUDY OF SIGNALLING GAMES ON THE LABOUR FORCE MARKET OF EU-27, THE PURE STRATEGY CASE

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Abstract:

The paper addresses several key issues in the field of game theory, namely: determination of the perfect Bayesian equilibrium for signaling games - the pure strategy case; signaling on the labor force market; application of the signaling game on the labor force market of EU-27.

The analysis of the perfect Bayesian equilibrium for signaling games - the pure strategy case has lead to the following conclusion: if the Sender strategy is unifying or separating then the equilibrium will be called unifying or, respectively separating.

In the section Signaling on the labor force market, there are issues regarding the complete information case, where we suppose that the worker's ability is common information for all players, but also issues regarding the incomplete information case. ***Three types of perfect Bayesian equilibriums may exist in this last model: unifying equilibrium, when both types of workers choose a single type of education; separating equilibrium, when the perfect Bayesian equilibrium is separating by itself, and hybrid equilibrium**, if a worker chooses a level of education with certainty, the other one may randomly choose between joining the fist one (by selecting the level of education of the first type) and getting separated from him (by selecting a different level of education).*

This analysis allows us to draw the following conclusions: in case of signaling games on the labor force market, the pure strategy case, three types of equilibriums are available: unifying, separating and hybrid; as the worker's ability is private information, this allows a low ability worker to pretend to be a high ability worker; the low ability workers find it more difficult to accumulate additional education requiring higher wages in return; besides the classical separating equilibrium, same as for the unifying equilibrium, there are other separating equilibriums implying a different educational choice by the high ability worker; sometimes the separating equilibrium becomes the limit of the hybrid equilibrium.

The application is meant to strengthen, at least partially, given the lack of consistent data, the theoretical results.

Key words: *signalling games, feasible strategy class, perfect Bayesian equilibrium, incomplete information, sender, receiver, labour force market, competition among companies*

JEL Classification: C71, C72, C73

1. INTRODUCTION

The principles of the game theory have been formulated for the first time during the `40ties by J. von Neumann and O. Morgenstern in the paper *Theory of Games and Economic Behaviour*.

Subsequently, this field has undergone an accelerate development mainly due to the contributions of Nash, J. F. (1950), Aumann, R. J. (1959), Harsanyi, J. C. (1970), Selten, R. (1975), Milgrom, P. and Stokey, N. (1982), Kreps, D. and Wilson, R. (1982), Aumann, R.J. (1990), Fudenberg, D. and Tirole, J. (1991), Reny, P. (1992), Ben-Porath, E. and Dekel, E. (1992), Banks, J., Camerer, C. and Porter, D. (1994), Kreps, D.M. and Sobel, J. (1994), Ben-Porath, E. (1997), Abreu, D. and Gul, F. (2000), Binmore K., McCarthy, J., Ponti, G., Samuelson L., and Shaked, A.(2002), Benaım, M. and Weibull, J. (2003), Benz, A., Joager, G., and Van Rooij R.(2005), Roth, A. E. (2007), Josephson, J. (2008), Balkenborg, D., Hofbauer, J., and Kuzmics, C. (2009).

2. DETERMINATION OF THE PERFECT BAYESIAN EQUILIBRIUM AS FOR THE SIGNALLING GAMES, THE PURE STRATEGY CASE

These types of games suppose the presence of two players, namely:

- the leader, the one who holds the private information, also called signal sender, E;
- the follower, the one who receives the information sent by the leader (sender), also called signal receiver, R.

Definition 1. The **signalling game** is a dynamic game with incomplete information where new data are added and existing information is completed.

The following steps are taken when performing the game:

P₁. Nature chooses a type t_i for the signal sender, E, out of a set of feasible types $T=(t_1,t_2,...,t_i,...,t_I)$ according to the probability distribution $p(t_i)$, where $p(t_i)>0$ for any i and $p(t_1)+p(t_2)+...+p(t_i)+...,+p(t_I)=1$.

P₂. The signal sender notice the type t_i and chooses a message m_j out of a class of feasible messages $M=(m_1,m_2,...,m_j,...,m_J)$.

P₃. The signal receiver notice the message m_j (but not the type t_i) and chooses an action (strategy) s_k out of a class of feasible actions $S=(s_1,s_2,...,s_k,...,s_K)$.

The results are a function of $\pi_E(t_i,m_j,s_k)$, for the signal sender, respectively $\pi_R(t_i,m_j,s_k)$, for the signal receiver.

Remarks: 1. Sometimes the classes *T*, *M* and *S* are intervals;

2. The feasible message class depends on the nature choice type, while the feasible strategy class depends on the message selected by the signal sender, E.

Figure 1 renders an extended representation of a simple case: $T=(t_1,t_2)$, $M=(m_1,m_2)$, $S=(s_1,s_2)$ and $\Pr ob(t_1)=p$.

In signalling game:

- a pure strategy for the signal sender, E, is a $m(t_i)$ function specifying the message to be selected for each type that the environment may choose;

a pure strategy for the signal receiver, R, is a $s(m_j)$ function specifying the action to be selected for each message that the sender may send.

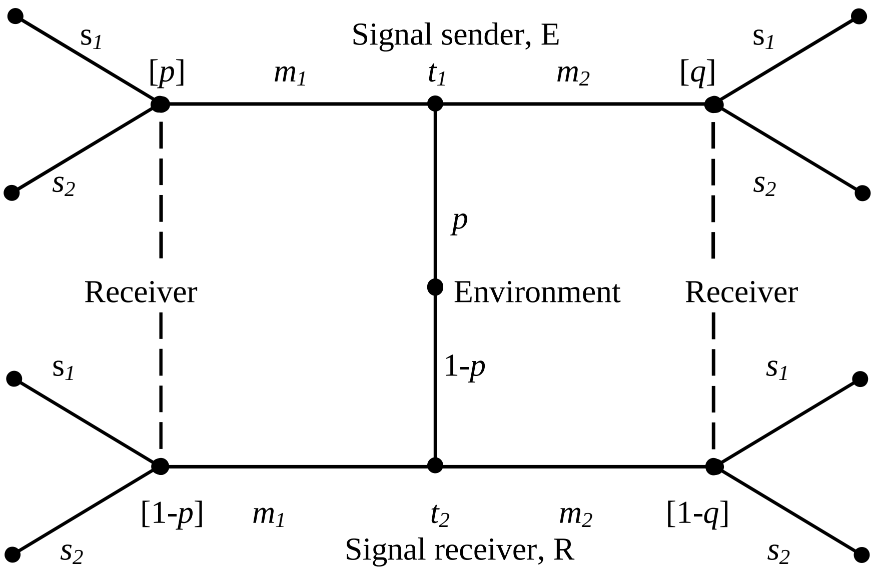

Figure no. 1.

Figure 1 renders a simple game where the Sender and the Receiver benefit, each of them, by four pure strategies:

- *Strategy of Sender 1:* plays m_1 if the environment chooses t_1 and plays m_1 if the environment chooses t_2;
- *Strategy of Sender 2:* plays m_1 if the environment chooses t_1 and plays m_2 if the environment chooses t_2;
- *Strategy of Sender 3:* plays m_2 if the environment chooses t_1 and plays m_1 if the environment chooses t_2;
- *Strategy of Sender 4:* plays m_2 if the environment chooses t_1 and plays m_2 if the environment chooses t_2;
- *Strategy of Receiver 1:* plays s_1 if the Sender chooses m_1 and plays s_1 if the Sender chooses m_2;
- *Strategy of Receiver 2:* plays s_1 if the Sender chooses m_1 and plays s_2 if the Sender chooses m_2;
- *Strategy of Receiver 3:* plays s_2 if the Sender chooses m_1 and plays s_1 if the Sender chooses m_2;
- *Strategy of Receiver 4:* plays s_2 if the Sender chooses m_1 and plays s_2 if the Sender chooses m_2.

Comments:

- the first and forth strategy, at the Sender level, are called *unifying* strategies, as each type sends the same massage;
- the second and third strategies, at the Sender level, are called *separating* strategies, as each type sends a different message;
- there are also the models with more than two types to be selected by the environment, the so-called *partially unifying* strategies, where all types belonging to a given type set send the same message, but different type sets send different messages;
- as for the game with two types to be selected by the environment (see Figure 1), we also have mixed strategies (*hybrid* strategies), where t_1 plays m_1 but t_2 randomly chooses between m_1 and m_2.

Signalling criterion 1: *After having noticed any massage m_j out of M, the Receiver shall have a certain confidence on the types that could have sent m_j. The probability distribution $\rho(t_i / m_j)$ shall be attached to this confidence,* where $\rho(t_i / m_j) \geq 0$, *for each t_i out of T, and* $\sum_{t_i \in T} \rho(t_i \mid m_j) = 1.$

Signalling criterion 2R: *For any message m_j out of M, The Receiver strategy $s^*(m_j)$ shall maximize the expected utility of the Sender, given the confidence $\rho(t_i / m_j)$ on the types that could have sent m_j, this meaning that $s^*(m_j)$ solves the optimum problem:* $\max_{s_k \in S} \sum_{t_i \in T} \rho(t_i \mid m_j) \pi_R(t_i, m_j, s_k).$

Signalling criterion 2E: *For each t_i out of T, the Sender message $m^*(t_i)$ shall maximise his utility, given the Receiver strategy $s^*(m_j)$, this meaning that $m^*(t_i)$ solves the optimum problem* $\max_{m_j \in M} \pi_S(t_i, m_j, s^*(m_j)).$

For the messages of the equilibrium class, by applying the third criterion to the Receiver confidence, we will obtain:

Signalling criterion 3: *For each message* m_j *out of M, if there is any* t_i *out of T so that* $m^*(t_i) = m_{i\,j}$, *then the confidence of the Sender as to the set of information corresponding to* m_j *shall follow the Bayes rule and the Sender strategy, therefore its probability distribution being rendered by*: $\rho(t_i \mid m_j) = \dfrac{p(t_i)}{\sum_{t_i \in T_i} p(t_i)}$.

Definition 2. *A pure strategy represents a* ***perfect Bayesian equilibrium in a signalling game****, if the triplet* $[m^*(t_i); s^*(m_j); \rho(t_i / m_j)]$ *complies with the signalling requirements* (1), (2R), (2E), and (3).

Conclusions:

1. If the Sender strategy is unifying or separating then the equilibrium will be called *unifying* or, respectively, *separating*.

2. The four possible pure strategies rendered by Figure 1, representing perfect Bayesian equilibria in this game with two types to be selected by the environment, and two messages are: (1) unifying on m_1; (2) unifying on m_2; (3) separating with t_1 playing m_1 and t_2 playing m_2; and (4) separating with t_1 playing m_2 and t_2 playing m_1.

3. SIGNALLING ON THE LABOUR FORCE MARKET

Corroborating with the steps taken in performing the signalling game, described at point 2, the carrying out of such a game on the labour force market looks as follows:

P$_1$. The environment determines the productive ability of a worker, θ, which may be high, *H*, or low, *L*,. The probability for $\theta = H$ is *p*;

P$_2$. The worker discovers his ability and selects a level of education, $e \geq 0$;

P$_3$. Two companies notice the worker education (but not his ability) and simultaneously advances wage offers to the worker;

P$_4$. The worker accepts the biggest of the wage offers.

We go further from the ascertaining that the wages are higher, on average, for those workers with many years of studies. This tempts us to construe the variable *e* as years of studies, the differences within *e* being seen as differences in the performance quality of a student and not as his individual length of studies.

As such, *e* measures the number and types of the subject matters assumed and the calibre of the marks and distinctions acquired all along an academic programme. The school attendance costs, if any, are supposed to be independent of *e*, so that the cost function $c(\theta, e)$ measures non-monetary or psychical costs.

The main assumption of the model is that the workers with low ability find the signalling more expensive than those with high ability. Therefore, the education marginal cost is higher for the low ability workers than for the high ability ones: for each *e*, $c_e(L, e) > c_e(H, e)$, where $c_e(\theta, e)$ represents the marginal cost for a worker with ability θ and level of education *e*.

In order to construe this assumption, we take a worker with the level of education e_1, to which a wage w_1 will be paid. The increase of the wages necessary in order to compensate this worker for an increase in education from e_1 to e_2 shall be also calculated. The answer depends on the ability of the worker: the low ability workers find it more difficult to accumulate additional education requiring higher wages in return.

Competition between companies turns the expected profits to zero. One way to deal with this hypothesis is to replace the two companies at **P$_3$** with a single player – the market, which makes just one wage offer w and gets the profit $[q(\theta, e) - w]^2$.

In order to maximize the expected earning, as required by the Signalling criterion 2R, the market shall offer a wage equal to the expected production of a worker with education *e*, given the market confidence on the worker ability, after having noticed *e*:

$$w(e) = \rho(H/e)\cdot q(H,e) + [1-\rho(H/e)]\cdot q(L,e) \qquad (1)$$

where $\rho(H/e)$ is the market assessment on the probability for the worker ability to be *H*.

Complete information case

We suppose that the worker ability is common information for all players. Thus, the competition among the two companies at $\mathbf{P_3}$ involves the fact that a worker with ability θ and education *e*, gets a wage $w(e) = q(\theta, e)$.

Therefore, a worker with ability θ, chooses the level of education *e* for solving the optimum problem: $\max_e\{q(\theta,e) - c(\theta,e)\}$

With the solution $e^*(\theta)$ and therefore $w(\theta) = q(\theta, e^*(\theta))$.

Incomplete information case

Returning to the assumption that the worker ability is private information, this opens the possibility for a low ability worker to pretend to be a high ability worker.

Two cases may rise:

- the first case where $w^*(L) - c[L,e^*(L)] > w^*(H) - c[L,e^*(H)]$;
- the opposite case, where the low ability worker is supposed to envy the wage offered within the complete information case and the education level of the high ability worker, this meaning that:

$$w^*(L) - c[L,e^*(L)] < w^*(H) - c[L,e^*(H)].$$

Three types of perfect Bayesian equilibria may exist in this model:

- unifying equilibrium, when both types of workers choose a single type of education, called e_d. The Signalling criterion 3 implies that the company confidence after having noticed e_d shall be the priority confidence, $\rho(H/e) = p$, implying that the wage offered after having noticed e_d shall be

$$w_d = p\cdot q(H,e_d) + (1-p)\cdot q(L,e_d) \qquad (2)$$

In order to complete the description of a unifying perfect Bayesian equilibrium, we shall:

- specify the confidence of the companies $\rho(H/e)$ for educational choices $e \neq e_d$ outside the steady state, determining the remainder of the strategies of the companies $w(e)$ by (1);
- demonstrate that the best answer of both types of workers to the strategy $w(e)$ of the companies is to choose $e = e_d$.

Thse two steps represent the Signalling criterion 1, respectively 2E, as above-mentioned.

If the company confidence is

$$\rho(H|e) = \begin{cases} 0 \ \ if \ \ e \neq e_d \\ p \ \ if \ \ e = e_d \end{cases} \qquad (3)$$

Then (1) determines the company strategy as

$$w(e) = \begin{cases} q(L,e) \ \ if \ \ e \neq e_d \\ w_d \qquad if \ \ e = e_d. \end{cases} \qquad (4)$$

Therefore, a worker with ability θ chooses the level of education *e* to solve the optimum problem:

$$\max_e\{w(e) - c(\theta,e)\} \qquad (5)$$

With the solution e_d or that *e* representing the solution of the optimum problem $\max_e\{q(L,e) - c(\theta,e)\}$.

Thus

- the triplet $[e, \rho(\theta), w(e)]$, $[e(L) = e_d; e(H) = e_d]$ representing the strategy of the worker, the confidence $\rho(H/e)$ given by relationship (3) and the strategy $w(e)$, for companies, given by (4), form a unifying perfect Bayesian equilibrium;
- by replacing e_d by $\tilde{e}$ within the relationships (3) and (4), the resulting confidence and the company strategy, beside the strategy $[e(L) = \tilde{e};\ e(H) = \tilde{e}]$ for the workers, represent another unifying perfect Bayesian equilibrium.

- **separating equilibrium**, when the perfect Bayesian equilibrium separating by itself implies the strategy $[e(L) = e^*(L); e(H) = e^*(H)]$ for the worker. The Signalling criterion 3 determines the confidence of the company after having noticed any of the two levels of education (namely, $\rho(H/e^*(L)) = 0$ and $\rho(H/e^*(H)) = 1$), so that (1) implies that $w(e^*(L)) = w^*(L)$ and $w(e^*(H)) = w^*(H)$.

In order to describe these separating perfect Bayesian equilibria, we shall:

- specify the confidence of the companies $\rho(H/e)$ for educational choices outside the steady state (values of e different from $e^*(L)$ or $e^*(H)$), subsequently determining the remainder of the strategy $w(e)$ of the companies by (1);
- demonstrate that the best answer for a worker with ability θ to the strategy $w(e)$ of the companies is to choose $e = e^*(\theta)$.

A confidence meeting these requirements is given by:

$$\rho(H \mid e) = \begin{cases} 0 \text{ if } e < e^*(H) \\ 1 \text{ if } e \geq e^*(H). \end{cases} \tag{6}$$

And the company strategy becomes:

$$w(e) = \begin{cases} q(L,e) \text{ if } e < e^*(H) \\ q(H,e) \text{ if } e \geq e^*(H). \end{cases} \tag{7}$$

As $e^*(H)$ is the best answer of the high ability worker to the wage function $w = q(H, e)$, this remains the best answers in this case too.

As for the low ability worker, $e^*(L)$ is the best answer of that worker when the wage function is $w = q(L, e)$, so that $w^*(L) - c[L, e^*(L)]$ represents the biggest earning the worker is able to reach, out of all choices of $e < e^*(H)$.

A specification of the confidence of the companies outside the steady state class, supporting this equilibrium-related behaviour, is that the worker has a high ability if $e \geq e_d$ and a low ability otherwise, the probability distribution being given by:

$$\rho(H \mid e) = \begin{cases} 0 \text{ if } e < e_d \\ 1 \text{ if } e \geq e_d. \end{cases}$$

The company strategy becomes $w(e) = \begin{cases} q(L,e) \text{ if } e < e_d \\ q(H,e) \text{ if } e \geq e_d. \end{cases}$

Given this wage function, the low ability worker answers the best:

- by selecting $e^*(L)$ and earning $w^*(L)$;
- by selecting e_d and earning $q(H,e_d)$.

Same as for the unifying equilibria, there are other separating equilibria implying a different educational choice by the high ability worker.

For exemplification, let $\tilde{e}$ be an educational level higher than e_d, but sufficiently low that the high ability worker would rather signal his ability by choosing $\tilde{e}$ than let other believe that he is a low ability worker: $q(H,\tilde{e}) - c(H,\tilde{e})$ is biggest than $q(H,e) - c(H,e)$ for any *e*.

If we replace e_d by $\tilde{e}$ in $\rho(H \mid e)$ and $w(e)$, then the resulting confidence and company strategy, beside the worker strategy $[e(L) = e^*(L); e(H) = \tilde{e}]$ are also a separating perfect Bayesian equilibrium.

Let consider, given the company confidence relating to the educational level, $e \in (e_d; e^*(H))$, as strictly positive but low enough, so that the resulting strategy $w(e)$ be placed under the indifference curve of the low ability worker, through point $(e^*(L); w^*(L))$.

- hybrid equilibrium

If a worker chooses a level of education with certainty, the other one may randomly choose between joining the fist one (by selecting the level of education of the first type) and getting separated from him (by selecting a different level of education).
We analyse the case when the low ability worker makes a random choice.

We suppose that the high ability worker chooses the level of education e_h (where h means hybrid), but the lo ability worker randomly chooses between e_h (with the probability π) and e_L (with the probability 1-π). The Signalling criterion 3 (rendered in the extended form in order to allow for mixed strategies) determines the company confidence after having noticed e_h or e_L, the Bayes rule leading to:[6]

$$\rho(H \mid e_h) = \frac{p}{p + (1-p)\pi} \tag{8}$$

and the usual conclusion after separation reduces to $\rho(H \mid e_L) = 0$.

4. APPLICATION OF THE SIGNALLING GAME ON THE LABOUR FORCE MARKET OF EU-27

Considering, at the level of several countries of EU-27, the following indicators:

Table no. 1.

	Education index 2007	e_d	H	L
France	0,978	0,852528	13,692	10,758
Spain	0,975	0,849528	13,65	10,725
Italy	0,965	0,839528	13,51	10,615
United Kingdom	0,957	0,831528	13,398	10,527
Germany	0,954	0,828528	13,356	10,494
Czech Republic	0,938	0,812528	13,132	10,318
Poland	0,952	0,826528	13,328	10,472
Hungary	0,96	0,834528	13,44	10,56
Bulgaria	0,93	0,804528	13,02	10,23
Romania	0,915	0,789528	12,81	10,065
Albania	0,886	0,760528	12,404	9,746

and identifying also the following functions:

$q(\theta, e) = a\theta^{\alpha} e^{\beta}$, for $\theta = L$, respectively $\theta = H$;

$c(\theta, e) = \dfrac{be}{\theta}$, for $\theta = L$, respectively $\theta = H$.

the results below have been obtained:
Complete information case

$$e^*(\theta) = \frac{a^2}{4b^2}\theta^3$$

Table no. 2.

	θ^* for $a = 1$, $b = 1$	θ^* for $a = 1/4$, $b = 3/4$
France	1,575602	3,277144
Spain	1,57399	3,27379
Italy	1,56859	3,262561
United Kingdom	1,564244	3,253521
Germany	1,562608	3,250118
Czech Republic	1,553824	3,231847
Poland	1,561515	3,247845
Hungary	1,565877	3,256917
Bulgaria	1,549394	3,222634
Romania	1,54102	3,205216
Albania	1,524566	3,170993

The highest level of ability, for both scenarios, is registered by France workers, followed by Spain, the lowest levels coming to Albania and Romania.
Incomplete information case

Table no. 3.

Unifying equilibrium 1				
eL	eH	roL=p	roH=p	w
0,852528	0,978	0,5	0,5	3,451499985
0,849528	0,975	0,5	0,5	3,440912561
0,839528	0,965	0,5	0,5	3,40562115
0,831528	0,957	0,5	0,5	3,377388022
0,828528	0,954	0,5	0,5	3,366800598
0,812528	0,938	0,5	0,5	3,310334341
0,826528	0,952	0,5	0,5	3,359742316
0,834528	0,96	0,5	0,5	3,387975445
0,804528	0,93	0,5	0,5	3,282101212
0,789528	0,915	0,5	0,5	3,229164096
0,760528	0,886	0,5	0,5	3,126819004

Table no. 4.

Unifying equilibrium 2				
eL	eH	roL=p	roH=p	w
0,852528	0,978	0,3	0,3	3,368363609
0,849528	0,975	0,3	0,3	3,358031205
0,839528	0,965	0,3	0,3	3,323589859
0,831528	0,957	0,3	0,3	3,296036783
0,828528	0,954	0,3	0,3	3,285704379
0,812528	0,938	0,3	0,3	3,230598226
0,826528	0,952	0,3	0,3	3,27881611
0,834528	0,96	0,3	0,3	3,306369187
0,804528	0,93	0,3	0,3	3,203045149
0,789528	0,915	0,3	0,3	3,151383131
0,760528	0,886	0,3	0,3	3,051503228

Tables 3 and 4 present the unifying equilibrium for two scenarios considered. It is ascertained that the highest level of *w*, for both scenarios is registered by France, followed by Spain, the lowest levels coming to Albania and Romania.

4. CONCLUSIONS

This analysis allows us to draw the following conclusions:

- in case of signalling games on the labour force market, the pure strategy case, three types of equilibrium are available: unifying, separating and hybrid;
- as the worker ability is private information, this allows for a low ability worker to pretend to be a high ability worker;
- the low ability workers find it more difficult to accumulate additional education requiring higher wages in return;
- beside the classical separating equilibria, same as for the unifying equilibria, there are other separating equilibria implying a different educational choice by the high ability worker;
- sometimes the separating equilibrium becomes the limit of the hybrid equilibrium.

The above-rendered application is meant to strengthen, at least partially, given the lack of consistent data, the theoretical results.

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