FEP WORKING PAPERS

Research – Work in Progress – nº164, January 2005

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ANIMALS DOMESTICATION AND AGRICULTURE AS OUTCOMES OF COLLUSION

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Abstract. Although it is know that there are circumstances where the competitive situation does not promote social welfare maximization, collusion is usually associated with firms' strategies that decrease welfare. In this paper, using the theoretical framework of the industrial organization, I demonstrate in a model with two sectors that the economic revolution induced by the animal domestication and the agriculture is an outcome from the strengthen in collusion between human beings in the course of historical time and not vice-versa.

Keywords: Collusion, welfare progress, domestication and agriculture emergence.

JEL: O13, Q34, Q57

1. INTRODUCTION

In industrial organization, collusion is associated with firms' strategies that decrease the social welfare, being indispensable its persecution by public authorities, Posner (1975). Nonetheless, it is conjectured since Schumpeter (1942) that the static efficiency that perfect competition promotes decreases the dynamic efficiency because the imitation with no cost of the new technical discoveries makes unprofitable to set substantial resources to R&D. And R&D is very important because "80 percent of the change in labour productivity (…) can be explained by 'technical change'" by itself, Solow (1957). Being that, in general terms there is a trade-off between the dynamic social welfare gain from firms' collusion in R&D activities (research joint ventures) and the static social welfare loss induced by anti-competitive firms' behaviour. Sometimes it is acceptable a welfare lose in the short-term to improve the dynamic efficiency of the society, (Brod & Shivakumar, 1999, Vonortas, 2000).

In historical terms, I conjecture that welfare improvements of high magnitude are associated with collusion / cooperation (that is a more sympathetic word) increases between human beings. That is because evolution of society to higher levels of integration and cooperation that permits the decrease in defence expenditures, the labour division, investments in R&D and the exploration of economies of scale are only possible if there is increases in the collusion level between people.

My conjecture seems in accordance with data. Being that over time cooperation evolved, Axelrod (1984), in a non-monotonous path, the existence of ups and downs, peace and war, integration and disintegration, in the human society seems related to decrease in cooperation and trust between human beings.

In this paper, using the theoretical framework of the industrial organization, I demonstrate within a theoretical model with two sectors that the social revolution induced by the animal domestication and the agriculture emergence only was possible with the deepening of collusion between human beings. The collusion permits the emergence of private property that turns possible that each human being captures the benefits of resources devoted to agriculture and animals domestication.

In evolutionary terms, collusion between human beings deepens by the agglomeration of more and more individuals in groups, structuring a heterogeneous society cemented with variable intensity. Starting with the proximal family with strong ties, groups enlarged to clans, tribes, and so on, less coupled. Groups that by chance (as Darwinism proposes) turn more cooperative are, on average, more efficient that implies having a faster replicating rate. Being so, in a limited resources environment, on a long-term trend the less cooperative human groups becomes less numerous and the society as a whole evolves to a more cooperation *status quo*. Being so, the competition decreasing is a dynamic evolution process that occurs by the reduction in the number of groups.

Without loss, I use simpler algebraic assumptions. First, I assume that the society is homogeneous and collusion deepens by the decrease in competition between each pair off human beings. Second, I assume a long-term stable state (whatever that means in evolutionary terms), building up a comparative static analysis where there is no more dynamic evolution. Being so, the collusion level is exogenous to the model.

The model I present is more explicative than the Smith's (1975) model where it is assumed that agriculture is pre-existent to the decision of applying resources to it (plants have been selected and domesticated in a previous step). Comparing to TV documentaries, I assume that agriculture emergence is an evolutionary process that starts when humans destroy a single plant that wild animals dislike it and endorse its counterpart.

2. THE MODEL

There is a market with two sectors interrelated. In the vegetation sector human beings are producers using land and labour as inputs and animals are consumers. In the meat sector, animals are producers and human beings are consumers (hunters).

For the sake of simplicity it is not explicitly considered in the model that human beings eat vegetables. Nonetheless it may be understand each *kg* of meat as an equivalent weight of vegetables.

Assumption 1 – There is a territory divided in *B* land parcels of dimension normalised to one.

Assumption 2 – The human being *j* lives on the land parcel *j* where the vegetation level is *Vj* and there are *Aj* animals.

Assumption 3 – There is a parameter $x \in [0, 1]$ that measures the degree of collusion between human beings. When $\xi = 0$ there is no collusion and when $x = 1$ there is perfect collusion. The parameter *x* quantifies the exclusiveness of each land parcel to the human being that lives there.

Assumption 4 – Although *x* is endogenous to the human evolution dynamics, I assume a static analyses where it is exogenous.

Assumption 5 – There is common knowledge (no private knowledge), being the collusion level *x* perfectly enforced.

A) The vegetation sector

Assumption 6 – Human being produces vegetation using land and labour. Being that in each time instant there is the quantity *Vj* of vegetation and human being works in developing agriculture with intensity $L^a j$, then the vegetation production is $Gj > 0$ that is convex decreasing with *Vj* and concave increasing with $L^a j$:

$$Gj = G(Vj; L^a j) = \left(k_0 + k_1 \cdot \frac{L^a j}{1 + L^a j} \right) \cdot \frac{1}{1 + Vj} \tag{1}$$

Assumption 7 – Animals eat vegetation. In instant *t*, each one of the *Aj* animals eats vegetation, being *x* the proportion of the effort devoted to eat vegetation in the land parcel *j* plus the proportion $(1 - x)/B$ of the effort devoted to eat vegetation in every land parcel. In probabilistic terms, x measures the probability that in instant t the animal j is eating in the land parcel j. Being so, the total (expected) number of animals feeding in the land parcel j is:

$$\overline{A}j = Aj \cdot x + \sum_{i=1}^{B} Ai \cdot (1-x)/B \quad (2)$$

Assumption 8 – Each animal eating velocity $Ej > 0$ is concave increasing with the quantity of existent vegetation (it eats more if there is more to eat) and convex decreasing with the number of animals that feed in that land parcel (there is competition between animals for vegetation):

$$Ej = E\left(Vj; \overline{A}j\right) = k_2 \cdot \frac{Vj}{\overline{A}j + Vj} \quad (3)$$

The vegetation net growth velocity in the land parcel j is the difference between the production Gj and the consumption Ej:

$$\dot{V}j = G\left(Vj; L^a j\right) - E\left(Vj; \overline{A}j\right) \cdot \overline{A}j \quad (4)$$

Understood $1/Vj$ as a “shadow price”, expression (1) represents the supply function that is increasing with price and expression (3) represents the demand function that is decreasing with price. Expression (4) models the market surplus and encompasses a dynamic adjustment “price” process.

When human being increases the agriculture intensity, there is a positive shift in the vegetation supply function that will imply a positive effect in the meat sector. It is comparable to a technological improvement in one sector that spreads out to all the economy.

B) The meat sector

Assumption 9 – The total vegetation an animal eats is the sum for all land parcels where it may feed:

$$\overline{E}j = E(Vj; \overline{A}j) \cdot x + \sum_{i=1}^{B} E(Vi; \overline{A}i) \cdot (1-x)/B \quad (5)$$

Assumption 10 - Each animal reproduces at the velocity Nj that is concave increasing with the vegetation that it eats. When an animal eats too little, it dyes of starvation, $N(0) < 0$:

$$Nj = N\left(\overline{E}j\right) = k_3 \cdot \frac{\overline{E}j - 1}{\overline{E}j + 1} \quad (6)$$

Assumption 11 – Human being j hunts animals in the land parcel j at velocity $Hj > 0$ that is convex increasing with the quantity of animals there is, Aj, linear increasing with the time devoted to hunt, L^h, and convex decreasing with the animals' ferocity, Fj:

$$Hj = H\left(L^h; Aj; Fj\right) = k_4 \cdot L^h \cdot \frac{Aj}{1+Aj} \cdot \frac{1}{1+Fj} \tag{7}$$

Assumption 12 – Human being j devotes $L^h j$ work effort to hunting. He utilizes the percentage x of the total hunting effort in the land parcel j and the unspent percentage $(1–x)$ of the total hunting effort in all land parcels (remember that x may well be interpreted as a probability):

$$\overline{H}j = H\left(L^h j \cdot x; Aj; Fj\right) + \sum_{i=1}^{B} H\left(L^h j \cdot (1-x)/B; Ai; Fi\right) \tag{8}$$

The total number of animals from land parcel j that are hunted is:

$$Hj = H\left(L^h j \cdot x; Aj; Fj\right) + \sum_{i=1}^{B} H\left(L^h i \cdot (1-x)/B; Aj; Fj\right) \tag{9}$$

As the hunting technology is linear in the effort devoted to hunting, assumption 10, being $\overline{L}^h j$ the total effort devoted to hunting in land parcel j by all human beings, it becomes:

$$\overline{H}j = H\left(L^h j \cdot x; Aj; Fj\right) + \sum_{i=1}^{B} H\left(L^h j; Ai; Fi\right) \cdot (1-x)/B \tag{10}$$

$$Hj = H\left(\overline{L}^h j; Aj; Fj\right) \tag{11}$$

The net animals' growth velocity in the land parcel j is the difference between the production $Nj \times Aj$ and the consumption Hj:

$$\dot{A}j = N\left(\overline{E}j\right) \cdot Aj - H\left(\overline{L}^h j \cdot x; Aj; Fj\right) \tag{12}$$

Assumption 13 – Human beings may decrease the animals' ferocity by using domesticating with intensity $L^d j$, being this technology convex decreasing:

$$Fj = F\left(L^d j\right) = k_5 \cdot \frac{1}{1+L^d j} \tag{13}$$

This assumption results from accepting that domestication results from an ecological evolution: some animals have a slightly higher ferocity level than others; when a high ferocity level animal is hunted, on average the animal population evolves to a less ferocity level and vice-versa. The extra effort used in hunting an animal that is fiercer than the average is the domestication intensity. In evolutionary terms, this permits humans to set the animals level of ferocity.

Understood $1/Aj$ as a “shadow price”, expression (6) represents a supply function that is increasing with price and expression (7) represents a demand function that is decreasing with price. Expression (12) models the market surplus and encompasses a dynamic adjustment “price” process.

When human being increases the domestication intensity, there is a positive shift in the meat demand function. It is equivalent to an increase in income.

Resuming, the model condenses that in each time instant human being j sets $L^h j$ effort devoted to hunting, $L^a j$ effort devoted to agriculture and $L^d j$ effort devoted to animals’ domestication. From this decision, it results a certain level of consumption $\overline{H}j$ that is dependent of the other human beings decisions and the collusion level x between human beings:

$$\overline{H}j = \overline{H}(L^h j, L^a j, L^d j) \tag{14}$$

C) Human utility function

Assumption 14 – The utility function is increasing with consumption $\overline{H}j$. Although taking into account consumption in all periods, in a stead state, the utility function is assumes to be:

$$U\left(L^h, L^a, L^d\right) = k_6 \cdot \overline{H}j \tag{15}$$

Assumption 15 – The human beings maximize the utility subjected to the “technology” $\overline{H}j$ and the total working effort Y:

$$v(Y) = \underset{L^h, L^a, L^d}{Max}\left\{U(L^h, L^a, L^d)\right\}, s.a. \begin{cases} \overline{H}j = \overline{H}(L^h, L^a, L^d) \\ Y = L^h + L^a + L^d \end{cases} \tag{16}$$

Assumption 16 – The decision of human beings is assumed in a condition of *Cournot-Nash* equilibrium: each human being sets the strategy that maximizes his utility assuming that all other human beings do not respond to changes in his strategy.

Assumptions 2, 5, 8 and 9 formalise that the competition decreases when x increases, being this perfectly enforced.

3. MAIN PROPERTY OF THE THEORY

As the emergence and development of agriculture and domestication is a long-term process, I assume a long-term stable state (whatever that means in evolutionary terms), building up a comparative static analysis where there is no more dynamic evolution. Being so, the collusion level is exogenous to the model. In a steady state, the velocity of variation of the quantities of vegetables and animals formalised in expressions 4 and 12 is zero.

Proposition – *When collusion between human beings increases, there is an increase in the effort devoted to agriculture and to the domestication of animals. This increase induces a raise in the quantity of vegetation, in the number of animals, a welfare improvement and a decrease in the animals' ferocity.*

Proof. First, I will compare the situation were human beings are perfectly colluded with the situation where human beings are in perfect competition. Second I simulate the in between evolution of the endogenous variables.

Perfect collusion (x = 1): Each human is monopolist in his land parcel.

Expressions (4) and (12) are a non-linear system with two variables, Vj and Aj that may be simplified:

$$\begin{cases} G(V,L) = E(V;A)\cdot A \\ N(E)\cdot A = H\left(L^h;A;F\right) \end{cases} \tag{17}$$

$$\Leftrightarrow \begin{cases} V = 0.5\cdot\left[-(k_2 - C_0/A) + \sqrt{(k_2 - C_0/A)^2 + 4\cdot k_2\cdot C_0}\right] \Big/ k_2 \\ A = 0.5\cdot\left[-C_2 + \sqrt{C_2{}^2 - 4\cdot\left[C_1\cdot(k_2+1) - (k_2-1)\right]\cdot V}\right] \end{cases} \tag{18}$$

$$\text{With } C_0 = k_0 + k_1\cdot\frac{L^a}{1+L^a};\, C_1 = \frac{k_4}{k_3}\cdot L^h\cdot\frac{L^d+1}{k_5+L^d+1};\, C_2 = C_1 - (k_2-1)\cdot V + 1 \tag{19}$$

Calibrated the constants, this non-linear equations system is easily computed by relaxation in a datasheet. Computed Aj, one obtain easily $\overline{Hj}$ by expression (10).

Perfect competition: Each human being is a tiny part of the total.

The action of a single human being does not improve the production of vegetation nor decreases the ferocity of animals. Being so, it is obvious that human being will employ all his effort hunting ($L^h = Y$, $L^d = 0$ and $L^a = 0$).

Calibration and simulation: I assume that $k_0 = 1$, $k_1 = 9$ (the agriculture improves the production of vegetables at most 10 times), $k_2 = 2$ (it scales the animals' technology of eating vegetable), $k_3 = 2$ (it scales the technology of producing meat), $k_4 = 1$ (it scales the technology of hunting animals), $k_5 = 10$ (it scales the ferocity of the animals), $k_6 = 332.8$ (normalised maximum utility to 100) and $Y = 5$ (it is the average number of hours per day that *OCDE*'s workers devote to work).

Using a Microsoft-Excel 2002™ datasheet, in the situation of perfect competition where $L^h = 5$, $L^d = 0$ and $L^a = 0$, it results from expression (17) that the vegetation production level is $G = 0.532$, the meat production level is $N = 0.126$, the ferocity level is $F = 10$ and the welfare level is $v(5) = 41.82$. Using the *Solver tools*, it results from the maximization of expression (17) that in perfect collusion $L^h = 2.930$, $L^d = 1.369$ and $L^a = 0.701$ that implies a vegetation production level $G = 1.499$, a meat production level $N = 0.301$, a ferocity level $F = 4.221$ and a welfare level $v(5) = 100.00$.

This two extreme situations show the appearance of domestications and agriculture when human beings pass from a situation of perfect competition to a situation of perfect collusion.

In the next figures I show that there is an monotonous increase in the working effort spent in agriculture, L^a and domestication, L^d with the increase level of collusion (fig.1) and that it is accompanied with an improvement in the welfare (fig.2). The model was implemented in *Microsoft - Visual Basic* 6.0 ™.

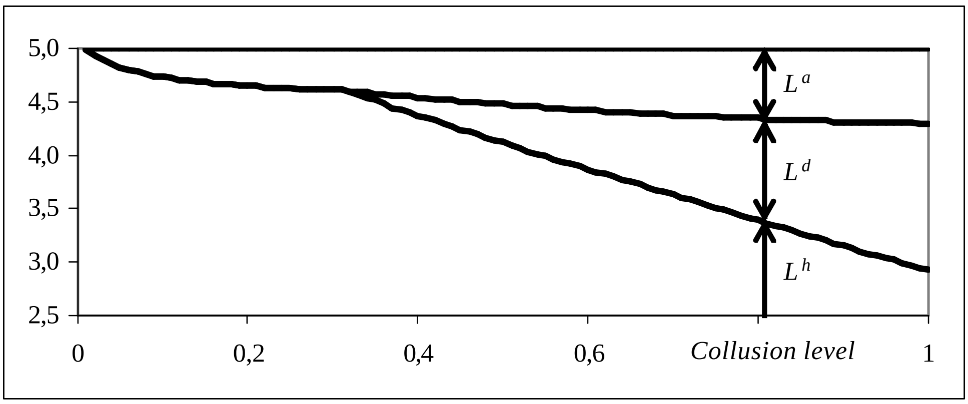

Fig. 1 – Working effort employed in agriculture, domestication and hunting

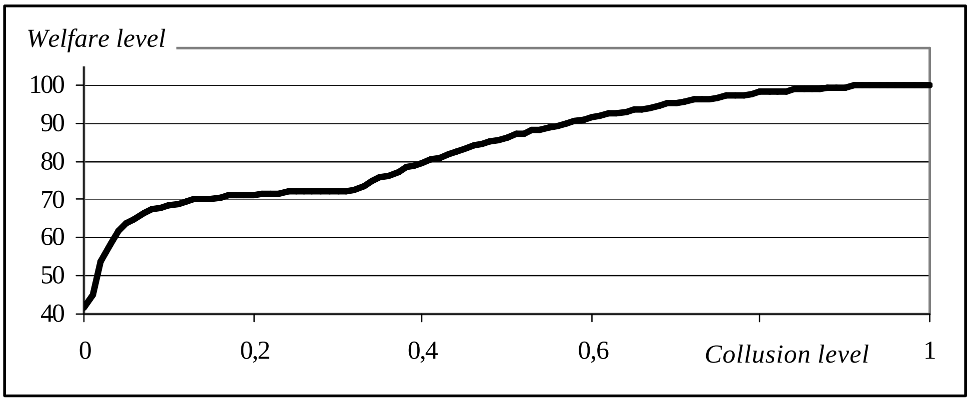

Fig. 2 – Welfare evolution with the increase in collusion level

Both comparing the two extreme situations and observing the simulation represented in figures 1 and 2, the increase in collusion between human beings promotes the appearance of the agriculture and domestication of animals and is associated with an improvement in the social welfare. QED

4. CONCLUSION

Collusion is normally associated with strategies that decrease the social welfare, being indispensable its persecution by public authorities. Nonetheless, it is conjectured at least since Schumpeter (1942) that the static efficiency that perfect competition promotes may decrease the dynamic efficiency because the imitation with no cost of the new discoveries makes unprofitable to affect substantial resources to *R&D*.

In this paper I demonstrate within a theoretical model that the animal domestication and the agriculture may be the outcome of increases in collusion level between human beings. The collusion permits the emergence of private property that turns possible that each human being captures the benefits of resources that he devotes to the development of agriculture and animals' domestication. Being so, it is not the economic development that promotes the evolution of the society to new levels of cooperation and pacification (increases in collusion) but the contrary: the cooperation and pacification of the society permits the economic development.

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APPENDIX

From equation system of expression (17) to expressions (18) and (19):

First equation

$$G(V;L^a) = E(V;A)\cdot A$$

$$\left(k_0 + k_1 \cdot \frac{L^a}{1+L^a}\right)\cdot \frac{1}{1+V} = k_2 \cdot \frac{V}{A+V}\cdot A$$

$$C_0 \cdot (A+V) = k_2 \cdot A\cdot V \cdot (1+V)$$

$$C_0 \cdot A + C_0 \cdot V = k_2 \cdot A\cdot V + k_2 \cdot A \cdot V^2$$

$$k_2 \cdot A\cdot V^2 + (k_2 \cdot A - C_0)\cdot V - C_0 \cdot A = 0$$

$$k_2 \cdot V^2 + (k_2 - C_0 / A)\cdot V - C_0 = 0$$

$$V = \frac{-(k_2 - C_0 / A) + \sqrt{(k_2 - C_0 / A)^2 + 4\cdot k_2 \cdot C_0}}{2\cdot k_2}$$

Second equation

$$N(E)\cdot A = H\left(L^h; A; F\right)$$

$$k_3 \cdot \frac{E-1}{E+1}\cdot A = k_4 \cdot L^h \cdot \frac{A}{1+A}\cdot\frac{1}{1+F}$$

$$k_3 \cdot \frac{(k_2-1)\cdot V - A}{(k_2+1)\cdot V + A} = k_4 \cdot L^h \cdot \frac{1}{1+A}\cdot\frac{L^d+1}{k_5+L^d+1}$$

$$\frac{(k_2-1)\cdot V - A}{(k_2+1)\cdot V + A} = C_1 \cdot \frac{1}{1+A}$$

$$\left[(k_2-1)\cdot V - A\right]\cdot(1+A) = C_1 \cdot \left[(k_2+1)\cdot V + A\right]$$

$$-(k_2-1)\cdot V - (k_2-1)\cdot V\cdot A + A + A^2 + C_1\cdot(k_2+1)\cdot V + C_1\cdot A = 0$$

$$A^2 + \left[C_1 - (k_2-1)\cdot V + 1\right]\cdot A + \left[C_1\cdot(k_2+1) - (k_2-1)\right]\cdot V = 0$$

$$A = \frac{-C_1 + (k_2-1)\cdot V - 1 + \sqrt{\left[C_1 - (k_2-1)\cdot V + 1\right]^2 - 4\cdot\left[C_1\cdot(k_2+1) - (k_2-1)\right]\cdot V}}{2}$$

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