ECONOMIC EVOLUTION AND UNCERTAINTY: TRANSITIONS AND STRUCTURAL CHANGES

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Abstract. Economic evolution is said to occur when economic structures change. That is, when the institutional and/or technological rules of the society are replaced by new ones. As with evolutionary phenomena in other fields it is rather impossible to predict such changes.

In this paper we present a simple model of evolutionary changes caused by uncertainty about the possible future states of the economy. Agents faced with uncertainty behave in such a way as to either lead the economy to another state or adjust themselves to the newly known environment. In either case, the change involves the modification of one or more fundamental parameters of the economy. Such modification is what we call an evolutionary change.

We prove an impossibility result, stating that there is no way of coordinating those adjustments as to make true any given forecast. Moreover, we show that uncertainty about the future is a real source of novelty.

1. Introduction. An economy, as a system, can be described by three “parameters”: its production structure (the web of production units and the current technology), its social-political structure (the set of rules regulating the interactions among agents) and the distribution of characteristics among the agents (their profiles of preferences and endowments). There exists a potential conflict between these parameters: the production and social-political structures constraint the outcomes of the economy while the distribution of characteristics defines the social goals. As outcomes may differ greatly from the social goals, instability may arise. If the gap is wide, a process of evolution operates, changing one or more of the conflicting parameters.¹

The most interesting cases are related to internal instabilities in the economy, particularly when agents change their minds, due to an improved knowledge of the economy. To justify this last claim we assume that agents have less than perfect rationality due to the costs of information gathering. Moreover, as the agents are

¹The conception of economic evolution formalized here differs in many aspects from more traditional views in the field. For surveys covering those notions see for instance [9] or [5].
aware of this, they may change their characteristics, during interactions, in response to new information.

On the other hand, the production structure can also be subject to changes. We focus here on technological changes (modifying the dimensionality of the system). These changes could be the result of the random generation of technological innovations but we assume that their adoption is a response to the preferences of the agents (ensuring the economic feasibility of the innovations). In the end, we will see that all the relevant changes can be traced back to variations in the state of knowledge of the agents.

Finally, the social-political rules change in response to variations in the aggregate knowledge in the economy. In the simplified version we present here we assume that these rules define the mechanism of resource allocation, which is mostly a symbolical system. Thus, the main changes can be retraced to the social knowledge acting on the rules through the characteristics of the agents.

In all these cases we assume that changes are solutions to an inherent conflict among parameters of the economy. We consider that a conflict arises when the outcome is not satisfactory according to at least one of the parameters. In a final analysis the relevant parameter is the distribution of characteristics of the agents.

Any particular state of the economy is only a metastable state of a complex process. The whole system goes from a metastable state to another, in response to shocks, guided by its internal dynamics. Since we assume that knowledge plays the crucial role here, it is rather natural to postulate that the main source of shocks is the uncertainty about the future states of the economy.

In our framework, uncertainty means that unexpected situations can arise. Our analysis emphasizes on the uncertainty intrinsically generated by the economy. Some of the parameters of the system must be modified in order to adjust the entire economy to the unexpected situation. This discontinuity in the time path of the economy is furthermore accompanied by a generic uncertainty about future values of the parameters. Therefore, exact prediction will be rendered impossible. This impossibility is the reason why evolutionary arguments are better fit for retrodiction than for the generation of testable statements.

One of the main motivations for this investigation is the pressing need to develop tools to face the challenges posed by future social, technological and fundamentally environmental events. In the latter case, consider the possible impacts of climate change. While some of its consequences can be foreseen, it constitutes in general a source of uncertainty. The environment is a complex system, with complicated self-control loops. This makes it hard to predict when and where and even whether any particular phenomenon will take place. As pointed out in [12], “models can tell us nothing about [...] the possibility of a catastrophic climate outcome”.

Consequently, specific changes induced by climate events on current economic systems cannot be predicted. But experts claim, with a high degree of confidence, that they will undergo substantial transformations. This calls for an extension of the characterization of economic systems as to capture their relations to the environment (physical as well as social) and the potential changes those systems may undergo.

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2This is close to the approach to institutional change embraced in [11]. Particularly relevant here is the conception of back and forth interactions between institutions and human cognition in the construction of its scaffolding [3].

3A similarly disruptive phenomenon is the so called technological singularity [1].
In this paper we present a formal characterization of the endogenous generation of evolutionary transitions in an economy due to uncertainty about the future. We analyze the dynamics of those transitions and derive a general impossibility result, concluding that there does not exist a coordination mechanism for the immediate adjustment of the parameters after the occurrence of an unexpected event.

The plan of the paper is as follows: in section 2 we introduce a general characterization of an economy, emphasizing the importance of the parameters; section 3 analyzes evolutionary transitions while in section 4 we derive our impossibility result. Section 5 concludes. Sections 2 and 3 reproduce the main definitions and results in [14], while the last part of section 3 recasts the notion of endogenous transition of [8]. Section 4 is the original contribution of this paper, which completes the main ideas in the aforementioned previous articles.

2. Representation of the economy. It is commonplace to represent an economy as a game-form. The idea underlying this approach is straightforward: an economy is constituted by interacting self-interested agents and game theory is the best analytical tool available for that kind of situations. However, interactions among agents are only a part of the whole characterization of an economy. The production structure is also relevant because it constraints economic outcomes. Moreover, political and social rules have as inputs not only the strategic decisions of agents, but also technological restrictions. We can give the following characterization:

**Definition 2.1.** The set of feasible states of an economy $\epsilon$ at time $t$ is denoted $\Sigma^t$ and the actual state is:

$$\epsilon^t = \langle I, X^t, \Theta^t, K^t, \Psi^t, R^t, \bar{c}^t, w^t, \bar{p}^t \rangle \quad (1)$$

where:

- $I$ is a fixed set of agents.
- $X^t$ is a compact subset in an $(l_t \times |I|)$-th Euclidean real space, where $l_t$ is the number of commodities at time $t$. This is the set of all feasible resource allocations at $t$.
- $\Theta^t \in \prod_{i \in I} \Theta_i$ is the *distribution of characteristics of the agents*, while $K^t = \prod_{i \in I} K_i^t$ describes the information held by the agents. For each $i$, $\Theta_i$ is the space of her possible types, and $K_i^t \subseteq \Sigma^{t+1}$ is the set of states of the economy that agent $i$ thinks possible for time $t+1$. To $\Theta^t \times K^t \times p^t$ corresponds a unique $\bar{c}^t \in X^t$. Each $\Theta_i^t$ provides a description of the preferences and endowments of agent $i$ while $K_i^t$ is $i$’s model of the economy, $\bar{c}_i^t$ is the bundle that $i$ desires to consume in period $t$ according to $i$’s type and beliefs. That is, $\bar{c}_i^t$ is $i$’s demand function.
- $\Psi^t$ is a compact correspondence, representing the *production structure* of the economy in such a way that:

$$x^{t+1} = \text{def} \ (w^{t+1} + \bar{c}^{t+1}) \in \Psi^t(w^t, p^t) \subseteq X^{t+1}$$

Given a vector of inputs, $w^t$ and their current prices $p^t$, $\Psi^t(w^t, p^t)$ is a compact set of possible outputs in the next period (obviously, only one element can be realized at $t + 1$).

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4 Notice that endogenous transitions are not conceived in the conceptions of evolutionary change in contemporary Life Sciences [4].

5 Capital letters, Latin and Greek, represent parameters, while lowercase ones represent variables.
• $R^t$ is an operator representing the social-political structure of the economy, such that for an outcome $x^t \in X^t$, $R^t(x^t, \bar{c}) = \langle w^t, c^t, p^t \rangle$. Given the output and the desired consumption, the rules indicate the prices at period $t$ and how the outcome will be shared among the agents and the production structure.

• $w^t \in X^t$ are the inputs for the production structure.

• $c^t$ is the bundle of commodities allocated to consumption.

• $p^t \in [0, 1]^t$ is the normalized vector of prices.

The “size” of $\Sigma^{t+1}$ indicates the uncertainty about the value that $\epsilon^{t+1}$ may adopt. In fact, a bigger $\Sigma^{t+1}$ implies a larger number of possible alternatives and, consequently, less certainty about the actual outcome. The natural way to formalize this intuitive notion is by endowing $\Sigma^{t+1}$ with a $\sigma$-algebra and then defining a suitable notion of measure. The details of this construction are irrelevant for our argument. What really matters is that each agent $i$ has to describe her knowledge of $\epsilon$ by means of a subset $K^t_i \subseteq \Sigma^{t+1}$. That is, $i$’s knowledge is represented by the set of states of the economy that $i$ thinks may occur at $t + 1$.

To represent the dynamics of $\epsilon$ we will give a previous definition:

**Definition 2.2.** An economy $\epsilon$ at $t$ has a history $\mathcal{E}^t$, a finite sequence of previous states of the economy, beginning at an arbitrary time $t_0$. That is, $\mathcal{E}^t = \{\epsilon^k\}_{t_0 \leq k \leq t}$ such that:

• If for a pair $k, k + 1$, $X^k = X^{k+1}$, $\Psi^k \equiv \Psi^{k+1}$, $\Theta^k = \Theta^{k+1}$ and $R^k \equiv R^{k+1}$, we say that the transition from $\epsilon^k$ to $\epsilon^{k+1}$ is smooth.

• If there exists $t_1$ such that the transitions are smooth for every $k, k + 1 > t_1$ we say that the economy converged to a stationary path.

We will conceive non-smooth transitions as induced by uncertainty. We will see that the realization of an unexpected state of $\Sigma^{t+1}$, due to environmental shocks or by internal conflicts among the different parameters of the economy, causes a non-smooth transition.

3. **Evolutionary dynamics.** An economy in a stationary path can change in time. Even so, the fundamental parameters remain static. An non-smooth transition, instead, represents a change in at least one of the fundamental characteristics of the economy.

We say that:

**Definition 3.1.** Given an economy $\epsilon$, for a pair $t, t + 1$, $\epsilon$ undergoes an evolutionary transition if the transition from $\epsilon^t$ to $\epsilon^{t+1}$ is non-smooth.

The environment of an economy consists not only of its natural environment, but also of other economies with which it interacts. The environmental factor is customarily represented as a random shock to the parameters. But in this case, shocks are not uniformly distributed and moreover, the parameters are not simply real numbers but structures. The representation we choose is the following:

**Definition 3.2.** An economy $\epsilon$ at $t$ has an environment given by $\mu_t$, a correspondence such that:

$$\mu_t : X \times \Theta \times \Psi \times R \rightarrow X \times \Theta \times \Psi \times R$$

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6This notion can be interpreted as “knowledge so far”. It is closer to the idea of belief.

7This approach is closely connected to possibility models in Epistemic Game Theory [2].

8This indicates that the economy is an open system that exchanges material and information with its environment.
where \( X \times \Theta \times \Psi \times R \) is the product space of parameters \((X^t \times \Theta^t \times \Psi^t \times R^t \in X \times \Theta \times \Psi \times R)\). \( \mu_t(X^t \times \Theta^t \times \Psi^t \times R^t) \subseteq X \times \Theta \times \Psi \times R \) is the feasible class of parameters at \( t + 1. \)

That is, the environment can change the parameters of the economy since here we assume that the economy is small compared with its environment. Otherwise, the economy could effectively change its environment. We say the economy is not feasible if its parameters are not in the feasible parameter space. The environment induces evolutionary transitions by making infeasible the status-quo and therefore forcing a change to allow the survival of the economy:

**Definition 3.3.** An economy \( \epsilon \) undergoes an evolutionary transition driven by the environment from \( t^i \) to \( t^{i+1} \) if \( X^t \times \Theta^t \times \Psi^t \times R^t \notin \mu_t(X^t \times \Theta^t \times \Psi^t \times R^t) \).

In words: an economy undergoes an evolutionary transition driven by the environment if the previous parameters are no longer feasible. This does not imply that an environmental change that allows the preservation of the status-quo cannot generate incentives for its demotion. However, this is a different kind of process in which the economy can settle on a point of \( \mu_t(X^t \times \Theta^t \times \Psi^t \times R^t) \). We call such situation an evolutionary transition endogenously driven. Potential reason for the latter kind of transitions are:

- Conflicts between different parts of the economy, even at a status-quo state.
- The possibility of improving the outcome, by a more efficient use of resources.

An analysis of the last case helps to clarify the former one, since endogenously driven transitions can be always traced back to conflicts among parameters. The standard way in which outcomes can be improved is through a coordinated action of all agents and firms. This is possible if the outcome is not efficient:

**Definition 3.4.** For \( t^i \) the outcome \( x^t = c^t + w^t \) is efficient if there does not exist an alternative \( c^t' \) such that for all \( i \in I \), \( c^t_i' \geq c^t_i \), with strict inequality for at least one \( i \), and there exists no other \( w^{t-1} \) (in \( t^{i-1} \)) such that \( w^{t-1} \geq w^{t-1} \) while \( x^t = (c^t + w^t) \in \Psi^{t-1}(u^{t-1}, p^{t-1}) \).

An efficient outcome \( x^t \) is called a potential output. Given an actual output \( x^t \) and the potential output that minimizes \(|x^t - x^t|\), \( \lambda^t = 1 - \frac{|x^t - x^t|}{|x^t|} \) as the rate of development of \( \epsilon \) at \( t \).

That is, an outcome is efficient and therefore a potential outcome of the economy if it responds to the choices of the agents with the minimal amount of inputs. The development rate indicates how far is the actual output from the nearest potential output.

Another way of improving the outcomes is by increasing the dimensionality of \( X^t \). But this has no effect unless the agents change their preferences (to include the new commodities in their preferred bundles), the production structure does not change to produce the new products and the system of rules is not modified to include ways to distribute the new goods. It follows that:

**Proposition 1.** If \( X^t \times \Theta^t \times \Psi^t \times R^t \) is a fixed point of \( \mu_t \) and \( \lambda^t \leq 1 \) there exists \( x^{t+1} \) such that \( \lambda^{t+1} = 1. \)

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\( ^9 \mu_t(X^t \times \Theta^t \times \Psi^t \times R^t) = \emptyset \) implies the immediate “extinction” of the economy.

\( ^{10} \) The Euclidean distance in \( X^t \). The minimum always exists because \(|\cdot|\) is a continuous function on the compact set \( X^t \).
Proof. Trivial. Since \( X^t \times \Theta^t \times \Psi^t \times R^t \in \mu_t(X^t \times \Theta^t \times \Psi^t \times R^t) \), the status-quo is feasible. Then let \( \bar{x}^{t+1} \) be a maximal element in \( \Psi^t(w^t,p^t) \setminus \{w^{t+1}\} \). It exists because it is an element in a compact subset of \( X^{t+1} \) with the partial order of its underlying Euclidean space. Then, by Zorn’s Lemma \( \Psi^t(w^t,p^t) \setminus \{w^{t+1}\} \) includes its maximal elements, each of which satisfies \( \lambda^{t+1} = 1 \.

This means that if the parameters remain feasible, the rate of development can increase without an evolutionary transition. Those transitions, instead, can be seen as the result of conflicts among parameter. These conflicts arise when outcomes or distributions prescribed by one of the parameters are incompatible with the prescriptions of other parameters.

As the set of allocations \( X \), the production structure \( \Psi \) and the social-political structure \( R \) exist to satisfy the requirements of economic agents, it seems that all conflicts can be finally solved in terms of their characteristics. We can say that the resolution of conflicts is a procedure that takes as input the characteristics of the agents and produces a social choice, a desired state of the economy. The types of the agents, in turn, can be changed by effect of their knowledge of the economy. We have, then, the possibility of a loop:

- characteristics of the agents \( \to \) feasible allocations, production structure, social-political structure \( \to \) economy \( \to \) knowledge \( \to \) characteristics of the agents.

When the agents coordinate their expectations, i.e. when \( \bigcap_{i \in I} K^t_i \subseteq \Sigma^{t+1} \), there does not exist a shock and therefore no change is induced. In that case, the parameters remain unchanged. Otherwise, a failure of coordination induces changes in the relevant parameters. A taxonomy of the change operators is as follows:

1. Changes in the characteristics of the agents, due to a better knowledge of the economy. We can represent this by means of an operator:
   \[ \phi_1 : \mathcal{K} \to \Theta \] (3)

2. Changes in the space of commodities: a previously unknown commodity becomes part of the set of possible choices of the agents. This can be represented as:
   \[ \phi_2 : \Theta \to X \] (4)
   and therefore:
   \[ \phi_2 \circ \phi_1 : \mathcal{K} \to X \] (5)

3. Changes in the production structure, due to changes in the space of commodities:
   \[ \phi_3 : X \to \Psi \] (6)
   and therefore:
   \[ \phi_3 \circ \phi_2 \circ \phi_1 : \mathcal{K} \to \Psi \] (7)

4. Changes in the political structure, given that the agents decide which “rules of the game” they want to change:
   \[ \phi_4 : \Theta \to R \] (8)
   then:
   \[ \phi_4 \circ \phi_1 : \mathcal{K} \to R \] (9)

\[ ^{11} \text{See a more thorough discussion of rules for changing rules in [15].} \]
We see here that knowledge propagates among the relevant parameters through the characteristics of the agents. We assume that the operators act in such a way that a change in $K_t$ defines the values of the parameters at $t + 1$. This is obviously very demanding, but we will keep this assumption, since it introduces little change in the main results we obtain and simplifies the presentation.

Knowledge affects the performance of the economy through its organizations. As long as they are willing to apply resources to induce changes, they will act successfully. Unless the state of knowledge remains stationary, all the parameters will be in permanent change. This is obviously not independent of the particular rules of the system. In general, those rules tend to avoid sudden changes: institutions are mainly concerned with providing stability to the system. On the other hand, it is also true that the state of knowledge changes from one period to the next. Its effects will depend on the nature of the relation between institutions and organizations.

To make this interaction among knowledge and rules precise we define a learning operator:

**Definition 3.5.** The learning operator $\gamma$ is such that:

$$\gamma : \{E_{t-1}\} \rightarrow K$$

where $\{E_{t-1}\}$ is the set of $e$’s possible histories up to $t-1$. If $e^t \in \bigcap_{i \in I} K_{t-1}^i$, $\gamma(E_{t-1}) = K^i$ and each $e^* \in \bigcup_{i \in I} K^i_t$ is such that its vector of parameters verifies that $X^* \times \Theta^* \times \Psi^* \times R^* = X^t \times \Theta^t \times \Psi^t \times R^t$.

The general representation of the process of endogenous evolution is therefore:

**Definition 3.6.** The transition operator $\Phi_0$ is:

$$\Phi_0 \equiv \langle \phi_1, \phi_2 \circ \phi_1, \phi_3 \circ \phi_2 \circ \phi_1, \phi_4 \circ \phi_3 \circ \phi_2 \circ \phi_1 \rangle \circ \lambda : \{E^t\} \rightarrow X^{t+1} \times \Theta^{t+1} \times \Psi^{t+1} \times R^{t+1}$$

This indicates that the previous history of the economy limits the selection of feasible future values of the parameters. Therefore:

**Definition 3.7.** An economy $\epsilon$ undergoes an evolutionary transition endogenously driven from $e^t$ to $e^{t+1}$ if $X^{t+1} \times \Theta^{t+1} \times \Psi^{t+1} \times R^{t+1} \neq \Phi_0(E^t)$.

A rather immediate consequence of this series of definitions is the following:

**Proposition 2.** If $e^t \notin \bigcap_{i \in I} K_{t-1}^i$, the economy undergoes an evolutionary transition endogenously driven.

**Proof.** Trivial: assume that $X^{t+1} \times \Theta^{t+1} \times \Psi^{t+1} \times R^{t+1} = \Phi_0(E^t)$, then the parameters at $e^{t+1}$ keep the values they had at $e^t$. Therefore, no change was induced (i.e. no $\phi_j$, $j = 1, \ldots, 4$ acted) and this means that no unexpected event happened. That is, $e^t \notin \bigcap_{i \in I} K_{t-1}^i$. Absurd.

This makes clear that uncertainty operates as the source of evolutionary transitions, either externally induced (because a sudden change of the environment) or internally generated. The question is, can those transitions be predicted?

4. **An impossibility result.** Proposition 2 states that the realization of an unexpected state of the economy induces an evolutionary transition. It is rather natural to assume that the surprise will last for a while and will be accompanied by a period of confusion and turmoil. In the terms of our model, this means that at least for one period after the shock, the knowledge of the agents cannot be coordinated. That is, there is no way that all agents agree in their expectations about the state of the
economy at $t + 1$ if the shock happened at $t$. In other words, it becomes impossible for them to predict the immediate future.

To show formally how this happens in our model, let us refine our description of the sequence of events that follows the realization of an uncertain event. We assume that

$$\Phi_0(\mathcal{E}^t) = f((s, a_1^{t+1}, \ldots, a_{|\mathcal{A}|}^{t+1}))$$  \hspace{1cm} (12)

where $s$ summarizes the effect on the parameters of factors that are not under the control of the agents, while for each $i$, $a_i^{t+1}$ is what we may call a corrective action performed in order to achieve certain goals. $f$ is a continuous function that indicates that the new state of the economy is fully determined by $s$ and the corrective actions of the agents. For one agent its action can be to adapt itself to the new situations while for another it may mean to profit from the new opportunities that arise.

A full coordination of expectations after the shock would mean that

$$\epsilon(f((s, a_1^{t+1}, \ldots, a_{|\mathcal{A}|}^{t+1}))) \in \bigcap_{i \in I} \mathcal{K}_i^t$$  \hspace{1cm} (13)

That is, to coordinate does not only mean to “have the same beliefs” but also do the right thing to make that belief true. It follows that

**Theorem 4.1.** After a shock at $t$ full coordination of values at $t + 1$ is impossible, i.e.

$$\epsilon(f((s, a_1^{t+1}, \ldots, a_{|\mathcal{A}|}^{t+1}))) \notin \bigcap_{i \in I} \mathcal{K}_i^t$$  \hspace{1cm} (14)

**Proof.** Let us assume that there exist an $\epsilon^* \in \bigcap_{i \in I} \mathcal{K}_i^t$ such that $\epsilon^* = \epsilon(\Phi_0(\mathcal{E}^t))$. But this means that the parameters of $\epsilon^*$, $X^* \times \Theta^* \times \Psi^* \times R^* = X^{t+1} \times \Theta^{t+1} \times \Psi^{t+1} \times R^{t+1}$. In other words, $X^{t+1} \times \Theta^{t+1} \times \Psi^{t+1} \times R^{t+1} = \Phi_0(\mathcal{E}^t)$. But since we assume that an evolutionary transition from $t$ to $t+1$ happens, $X^{t+1} \times \Theta^{t+1} \times \Psi^{t+1} \times R^{t+1} \neq \Phi_0(\mathcal{E}^t)$. Absurd.

To understand this result, notice that the parameters of the economy are indeed subject to coordination. That is, the main aspects describing the economy can be modified by the decisions made by economic agents. Preferences, production and political structures can be changed if enough agents agree on changing them. If unexpected shocks could produce a coordination of expectations, it could only happen if the agents had the same beliefs and could react all rationally and in the same direction. But if this happened, the agents could undo the effects of the shock by forecasting it, and thus making it expected. But this would contradict the “unexpectedness” of the shock. Therefore, no coordination ensues.

This result illuminates the internal structure of evolutionary phenomena. Not only it is not possible (by definition) to predict uncertain events, but also their effects on the future path of the economy. The source of the later unpredictability is the impossibility to coordinate expectations. If agents were capable to do that, this very fact would eliminate the evolutionary transition. It is the differential response of agents (their corrective actions) that leads to the change of parameters. A society of homogeneous agents would never experience evolutionary transitions (except for passive responses to changes in the environment). From Theorem 4.1 we see that our model discards, implicitly, this last case.

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12By an abuse of language we use a function $\epsilon(\cdot)$ whose domain is the parameter space, to indicate that the state of the economy results from the value of the parameter vector.
Interestingly, this result goes across the entire ontology of structural changes described in [5]. In that view, there are clear distinctions between operational (i.e. resource-related) and generic (institutions-related) analyses, as well as between micro, meso and macro transitions. In our conception, instead, we combine all of these levels, without making distinctions on the impact of the transitions, which affect all the hierarchy at the same time, allowing to higher order effects on the entire economy.

An additional question could be whether it is possible to design mechanisms to coordinate instantaneously the responses of the agents. This could be a goal for a social planner who wants to keep the society in a stationary state. But then, it is rather easy to show that the heterogeneity of the agents conspires against him. Unless there exists a strictly dominant action $a_i^{t+1}$ for each $i$ there is always possible to manipulate a mechanism, and worse yet, even if a vector of dominant strategies exists, it must be the one that leads to the same value of the parameters as the one intended by the mechanism.

5. Conclusions. In this paper we analyzed the notion of economic evolution and emphasized on uncertainty as its main source. We showed that evolutionary transitions arise either because of external shocks to the economy or due the severe failures in the knowledge the agents have about it. Moreover, we showed that the unpredictability of the future of the economy is another result. We discussed the source of the impossibility of forecasting and coordinating actions, showing that it is the heterogeneity of the agents.

More work is needed to analyze specific cases of evolutionary transitions, but the results presented here are generic and therefore apply to every case of evolutionary transition. In particular, given the looming threats of climate change and technological singularity, among other existential risks for mankind, the search of models of economic evolution triggered by uncertain events is a pressing necessity.

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