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The Overexploitation of Natural Resources in Arid Central Asia. The Case of Hungry Steppe: Can a Collapse be a Solution?

RESEARCH ARTICLE

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ABSTRACT

The paper aims to provide a postdictive answer to why Central Asia is continuously investing or aspiring to invest in irrigation infrastructure and further contributing to the overexploitation of renewable and non-renewable endowments of its steppe zones even when the conventional economic rationale loses its worth. The study devises its analytical framework around the Hungry Steppe case. The analyses explain such instances with the sunk-cost effect resulting from complexity investments as part of a positive feedback loop that eventually locked the Steppe in the intensive cropping system and land degradation. The paper justifies the discourse of the sunk cost role in the Hungry Steppe lock-in phenomenon using game modelling. The work presents two alternative scenarios based on its game-theoretic model. Both scenarios reveal that most strategic interactions between the State and resource users are subject to multiple equilibria under both bureaucratic and private arrangements. Though the private arrangement scenario expects better infrastructure, both keep locking the Steppe in the positive feedback loop of land degradation and intensive cropping. The paper provokes the discourse on alternatives to intensive cropping in the Steppe, suggesting the collapse of irrigated agricultural production practices to solve the vicious cycle of resource over-exploitation.

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Both scenarios, however, are locking Steppe in the intensive cropping as a major economic activity in the Steppe and increasing land degradation. Therefore, the paper suggests the collapse of irrigated agricultural production practices as a possible solution to the vicious cycle of resource depletion. Accordingly, the work initiates the discussion on a non-mutually exclusive and non-exhaustive list of alternatives to irrigated cropping in the Steppe or transition solutions, namely: (1) non-farm job creation, (2) voluntary resettlement programs, (3) direct payments, and (4) transhumant herding system.

Section two describes the paper's theoretical framework by dividing them into three fronts, which help generate one whole situational and hypothesised projectional picture for the Steppe. Section three presents the game-theoretic modelling of the Steppe. The following section presents the results of the analyses that narrate the Hungry Steppe case through the lens of the theory of complexity, positive feedback loop and then joins two lenses with the game theory. Moreover, the same section initiates the discussion on alternatives to irrigated agriculture in the Steppe. Section five discusses the model findings, derives the implications and concludes.

2. THEORETICAL FRAMEWORK

2.1. CONCEPTS OF COMPLEXITY AND COLLAPSE

Complex societies are problem-solving organisations. When instances require more parts in complex societies, greater social differentiation, greater inequality, and greater types of centralisations and control along with infrastructure supporting such complexity emerge (Tainter, 1988: p37).

It is more expensive to sustain more complex societies than to preserve simpler ones. The cost of sustaining complex societies keeps increasing, which further increases the complexity. Growth in complexity yields benefits such as resource storage, its distribution across resource users and hence expansion in their wellbeing, investment in agriculture, education, public works and so forth. The growth of benefits from complexity follows the curve as illustrated in Figure 1.[2]

In the investment continuum of complexity, as in Figure 1, there is a point (after B1-C1 point) when each incremental investment starts to bring a lesser amount of incremental benefit. At first, the decline is gradual, and then the process takes a higher speed. The figure states that when the ratio of benefits/investment is unfavourable, the phase which starts after B2-C2 point, further increasing the complexity with more investment (sunk cost) is not an economically justifiable strategy. After this point, the Society enters the phase where it becomes prone to collapse (Tainter, 1988: p120).

An alternative strategy to further increase the complexity is a collapse. ***Collapse*** is a process of decreasing complexity, and it emerges as another problem-solving mechanism, just like complexity. Any society may face collapse whenever the investments in complexity stop bringing benefits. For example, sedentary horticulturists (complex Society) may become mobile herders (simpler

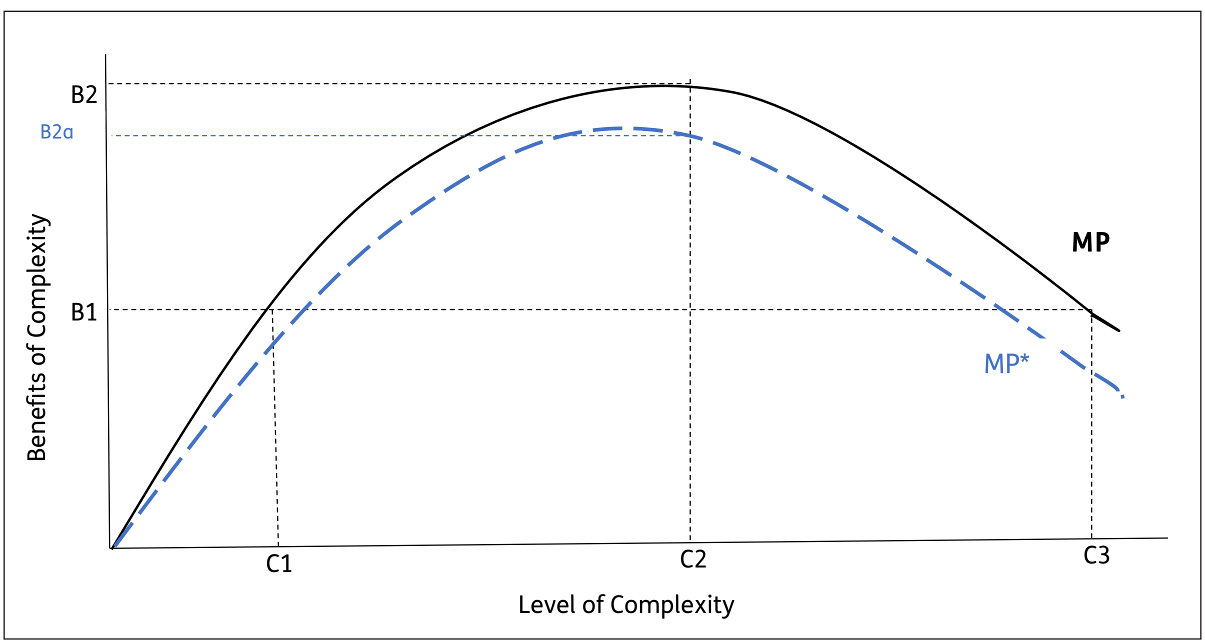

Figure 1 The marginal product of increasing complexity.
Source: Adapted from Tainter (1988: p119).

Society), and this transformation is one of the few solutions or collapse scenarios.[3]

In the case of Hungry Steppe, the paper refers to the culminating infrastructural solutions to the production objectives as growing in complexity. Collapse, in turn, is considered as a case when the investments in infrastructural solutions stop and intensive cropping fades away, and other economic activities besides the intensive cropping would emerge.

A study by Janssen & Scheffer (2004) is a good example that used Tainter's complexity, collapse and sunk cost concepts to explain the overexploitation of renewable resources by ancient societies. Based on their findings, the authors claimed that the way the current socio-ecological systems function is not sustainable, and "there are various psychological and economic reasons why our consumption pattern develops the way it does. Perhaps the sunk-cost effect may contribute to the explanation of why people continue to consume resources that are already overharvested" (p13). Our study furthers such methodological use by integrating Tainter's concept into the Steppes' positive feedback loop and game modelling. The following subsections provide more details on these.

2.2. FEEDBACK MECHANISMS, PATH DEPENDENCY, LOCK-INS, AND SUNK COST

The paper refers to the theoretical concept called *positive feedback*, also denoted as increasing returns (or reinforcing loop) in the literature (Arthur, 1994), which implies the possibility of *several equilibrium points* to analyse the Hungry Steppe's lock-in phenomenon. In this approach, unlike the conventional concept of diminishing returns (negative feedback or balancing loop), there is no guarantee that the particular economic outcome among the many alternatives will be the most efficient one.

There are two types of feedback processes in socio-economic systems. The first is the positive feedback loop, and the second is the negative feedback loop. Positive ones are *self-reinforcing* and generally are responsible for the growth or decline of systems. Negative feedback loops are *balancing* and represent goal-seeking processes. They can stabilise the system or apply corrective acts (Radzicki, 2021: p2). Negative feedback is associated with optimising behaviour which facilitates stable and predictable behaviour and is per the rational behavioural model (Joffe, 2021: p45). Both feedback mechanisms compete for dominance during the accumulation process, and the competition determines the details of the interaction between the trend and the cycle (Radzicki, 2021: p3).

"…once one accepts that [the system] is a feedback system of one particular type [positive or negative], it is a small step to recognising that other types can occur. This contrasts with some proponents of a complexity viewpoint, who see a dichotomy between standard theory and complexity economics." (Joffe, 2021: p62). There is a positive possibility of co-existence or interplay between standard theory[4] and complexity viewpoint[5] in heterodox dynamic economic system analyses (Radzicki, 2021: p3).

Once a random *path* is selected, the choice may become *locked-in* regardless of the advantages of the other options. Under the positive feedback concept of *multiple outcomes*, one needs to follow the process by which small *random historical events* cumulate to cause the system to fall toward one particular *self-reinforcing* outcome rather than the other alternative. The current concept's valuation of history as decisive in identifying the outcomes is called *nonergodicity* or *path dependency* (Arthur, 1994).

Whether a system is exposed to path dependency depends mainly on the system's capacity to provide positive feedback (Heinmiller, 2009). There is a variety of sources of positive feedback which has the potential to contribute to path dependency, such as (1) large fixed (sunk) costs; (2) potential network effects; (3) potential learning effects; and (4) adaptive expectations (Arthur, 1994). The current paper focuses on sunk cost element among other potential sources of path dependence. However, by doing so, the author does not mean other sources are not relevant to the nonergodicity of the Hungry Steppe lock-in phenomenon. On the contrary, they should be further researched.

The relevant sunk costs contributing to path dependency are investments in water governance rules and extensive water management infrastructure funded by the state budget (Heinmiller, 2009). In case of the rollback from the water-intensive economic activities, most of the grandiose water infrastructure becomes redundant. A similar case was observed with West American water infrastructure (Reisner, 1993). The unwillingness to abandon these sunk costs is a significant source of positive feedback (Heinmiller, 2009). This then locks the system in inferior convention and reinforces it.

The decision-makers in the past and present were subject to sunk cost effect and played a significant role in the lock-in phenomenon. In this way, the decisions keep increasing the complexity level and the costs associated with the increased complexity perpetuate further investments in complexity and so forth.

2.3. GAME THEORY: ROLE OF GAME THEORY IN INSTITUTIONAL ANALYSIS AND ITS CONSTRAINTS

By employing game-theoretic modelling, the paper prognoses the infrastructure investment behaviour of the State and the water users when there is a positive feedback loop sourced from sunk cost effect phenomenon.

Institutional studies which apply games as their analytical tool consider institutions either as equilibria (Greif, 1994: 943), as the shared beliefs motivating equilibrium play (Aoki, 2001: 10) or as the rules of the game (North, 1990: 4).

"Which characterisation of an institution to adopt is not an issue of right or wrong; instead, it depends on the purpose of the analysis" (Aoki, 2001: 10). The main objective here is to analyse the strategic infrastructure investment behaviour of Steppe stakeholders, such as water and land using community and the State, considering sunk cost effect possibility under various property right settings. Therefore, the analyses will consider the institutions as the rules of the game as defined by North (1990).

By altering the rules of the game, we figuratively indicate altering the institutional setting. Property rights that may be held by various claimants—the State, user groups, families, or individuals, are critical for the authority, incentives, and resource allocation for irrigation operation and maintenance (Meinzen-Dick, 2014). Such critical interlinkage between property rights and incentives to invest is accordingly reflected in the rules of the game model the paper devices. State ownership is reflected in the State's bearing of sunk cost attribute. Private ownership is reflected in a game rule where the resource user also incurs the sunk cost.

Game theory allows studying the relationship between game rules and self-enforcing behaviour. There are, however, limitations in game theory due to its strict assumptions. In games, a player's current and expected behaviour results from a predetermined strategy. Though conditioned on past events, all behaviours in the game are highly cognitive and forward-looking; players possess complete information about the consequences of their own decisions (Bowles, 2004: 53; Greif, 2006: 9). In the game-theoretic approach of institutional analyses, the biggest constraint is that no endogenous forces are causing institutional change. The classical game theory's platform is insufficient to analyse institutional dynamics (Greif, 2006: 10).

3. METHODOLOGY: STEPPE GAME WITH SUNK COST

3.1. BASIC GAME MODEL

This section illustrates the role of the sunk-cost effect in the vicious circle of the Hungry Steppe by devising a game model. The current modelling is adopted from Van Dame (1989) and tailors the game attributes to the location specificities. Player 1 is the State, and Player 2 is the Society representatives in Hungry Steppe. We present a simplified version of the rural livelihood setting in the Steppe to its essential features. This game is called the *battle of the sexes*. The story entailed that a husband and wife needed to decide whether to go to a boxing match or ballet. The husband was supposed to prefer the boxing match, and the wife chose the ballet. The solution depends on either spouse's strength of character. An efficient outcome, which avoids (0;0) payoff set, could only be attained through the compromise, where one had to accept a less desirable option (Dixit et al., 2014: 115). We rename the game as "Steppe Game". Table 1 presents the payoff matrix of this interaction.

The vast rolling plain of the Hungry Steppe, due to insufficient precipitation and little water influx through small streams from nearby mountains, letting only small scale and limited irrigated cropping. Otherwise, the rainfall does not fit rainfed agriculture, and large scale cropping activities are only possible with intensive irrigation (Bichsel, 2017). Both players want to use the land in the Steppe, but they prefer different uses. We assume that the State prefers to stick to intensive crop production where irrigating is a crucial input because of historical legacies and rent-seeking water bureaucrats. Meanwhile, because of the land degradation and poverty interlinkages, the Society prefers alternative Steppe land usage, not intensive cropping, which is detrimental to land degradation. For example, we can assume that the Society prefers to use the land as pastureland because pastures exploit the land extensively. At the same time, the livelihoods are improved, as supported by evidence in Neely et al. (2009). The current paper assumes that such an incentive structure of the local Steppe society is based on the historical practices of the region's local people. According to historical records, for many centuries, grassland and bushes of the Hungry Steppe, which was the case only during the early spring months, were mainly used by nomadic and transhumant pastoralism (Karavaev, 1914: p6; Bichsel, 2017). The Steppe experienced a radical change since late 19th century and was subject for externally (State) introduced large-scale land reclamation and irrigation development (Obertreis, 2017; Bichsel, 2017).

The game can only have an efficient solution (equilibrium) if either of the players accepts less desirable behaviour. In our modelling, the land-use efficiency is

PLAYER 1: STATE	PLAYER 2: SOCIETY	
	STRONG	***WEAK***
strong	(0; 0)	(3; 1)
weak	(1; 3)	(0; 0)

Table 1 Steppe Game.
Source: Adapted from the battle of the sexes payoff matrix.

measured with the total sum of both players' payoffs at a particular strategy set. The sum is maximized in the following strategy profiles: {*weak;strong*} or {*strong;weak*}. For the interaction to achieve efficient land use, either State or Society has to accept a *weak* (less desirable) strategy while the counterpart plays *a strong* (desirable) strategy.

In other words, there are two Nash equilibria, where no player can get a better payoff by switching to another strategy available while all the other players adhere to the equilibrium profile (Dixit et al., 2014: 95). If Society believes that the State will choose *strong,* it is best for the Society to choose the *weak* strategy and the other way around. Thereby the strategy profile {*strong,weak*} is a Nash equilibrium. For similar grounds, converting the Steppe into pasturelands with the strategy profile {*weak; strong*} is another equilibrium. If the State issues policies that prohibit converting the Steppe into the pastures, in other words, the State plays *strong*, then for the Society, it does not make sense to opt for *strong,* and the other way around. To attain either of these Nash equilibria and avoid the outcome where the State and Society opt for options as {*strong;strong*} or {*weak;weak*}, and the land is idle, there is a need for coordination and to break the symmetry.

According to the conventional economic theory, investment decision making should consider the marginal costs and benefits of the current options, and in this process, the sunk-costs are irrelevant (Varian, 2010: 574). However, many cases reveal that humans consider prior investments while making decisions (e.g., Clark et al., 1979; Janssen & Scheffer, 2004). Hence it is reasonable to integrate sunk cost into the decision-making game for the Hungry Steppe. According to Van Damme (1989), the amount of sunk-cost may determine which equilibrium is focal in the interactions.

3.2. SCENARIO A: THE ONLY STATE CAN INVEST

Consider the Steppe Game in Table 1 again. For more than a century, the Hungry Steppe's irrigation infrastructure has been an object of continuous state investments. Now we reflect on this pattern and assume that State can invest in irrigation infrastructure a certain amount of money before playing the Steppe Game. We term the amount as "***i***". Society does not have such an option of investing. Such exclusivity of investment accentuates the real context with the bureaucratic arrangement in the Steppe. Whether or not the State invested non-recoverable money in the infrastructure is common knowledge. Table 2 is a reduced normal form of the Steppe Game with an investment option in irrigation infrastructure.

Which outcome will follow from the game in Table 2 depends on the investment amount (i). For now, we assume i is exogenously determined, with a conditional value: $i >$ 0.25. According to the reduced normal form in Table 2, State can guarantee a payoff of 0.75 by not investing money in irrigation infrastructure and choosing its maximum strategy 0.25 *strong* + 0.75 *weak* (Table 1). This implies that *invest& weak* (investing in irrigation infrastructure and then choosing to be weak and allow the Society to use the land as pastureland) is a dominated strategy for the State. Hence it is not chosen (as part of State's best response play) (Dixit et al., 2014: 104).[6] Therefore, Society should conclude that State plays *strong* after it has invested ***i***. As a result, after State has invested in the irrigation infrastructure Society should respond by playing *weak* (as a rational player). In this case, the State gets (3–i) if it chooses to invest ***i***. This outcome takes place so long as Society pledges to a theory that declares that dominated strategies are irrational. However, this implies that the strategy *Doesn't & weak* is dominated if $i < 2$, such that Society should understand that State will play strong even when it does not invest in the irrigation infrastructure.

STATE	SOCIETY	
	STRONG	***WEAK***
Doesn't & strong	(0; 0)	(3; 1)
Doesn't & weak	(1; 3)	(0; 0)
invest & strong	(-*i*; 0)	(3-*i*; 1)
invest & weak	(1-*i*; 3)	(-*i*; 0)

Table 2 Reduced normal form.
Source: Adapted from Van Damme (1989).

So, when $0.25 < i < 2$**,** the strategy *Doesn't&strong* survives the successive elimination of dominated strategies. Even without investing in the infrastructure, the State still gets its desirable outcome (plays *strong*). Availability of an additional option (investment), even if it is not used, significantly affected the game's outcome. Without the sunk cost phase (as in Table 1), there were two equilibria; however, with sunk cost possibility and its exclusivity to the State, which is a reflection of bureaucratic institutional arrangement, it is prognosed that the State will not invest further. However, it will keep playing strong and locking the steppers further in the intensive cropping.

For other conditional values of i, however, the game's solution changes. For example, when $\boldsymbol{i} >$ **2.25**, then *invest &strong* and *invest &weak* strategies are dominated (eliminated) by the *maxmin* strategy,[7] such that additional options are irrelevant and the interaction reduces to the one in Table 1.

For the values $2 < i < 2.25$, when State invests it will play strong, and hence Society will play *weak* as a rational player. There are two strict equilibria in this game with the following payoff profiles: (3,1) and (1,3). There is, however, one more stable solution with a payoff profile (3–*i*, 1). Van Damme (1989: 489) refers to it as an "intuitively stable" solution. Because the Society is not certain what will the State choose if it does not invest in the infrastructure.

For the values $0 < i < 0.25$, the game in Table 2 does not admit dominated strategies. Instead, there are five subgame perfect equilibria paths: {*Doesn't&strong; weak*}, {*Doesn't &weak; strong*} and investing *i* followed by {*invest& strong;weak*} and {*invest&weak; strong*}. Following Van Dame (1989), the current paper claims that the stability criterion is met in the strategy profile: {*not invest& strong; weak*}. Because in this case, State receives its maximum payoff, and Society cannot signal a nonconformity. {*Doesn't&weak; strong*} is not stable. Because the State playing weak after investing is an inferior strategy, the Society should expect that the State will keep playing strong even when it does not invest. However, considering the conditional (small) value of the sunk cost [$i \ni (0, 0.25)$], we can say that the State will benefit from investing, as the payoffs are not harmed significantly.

If to summarise, as long as $0 \in i$, $i \ni (0.25, 2)$ and $i \neq \varnothing$, there is only one solution of the game in Table 2, and it is the case when the State *does not invest* and chooses to play *strong*, to which the Society responds by playing *weak* as it is the best response.

Below there are two scenarios, according to one the long-time persistent bureaucratic setting of the Steppe and according to another private property arrangement with the nested characteristic of the infrastructure are modelled.

3.3. SCENARIO B: BOTH CAN INVEST

Now let us consider the same interaction with only a difference where both State and the Society can invest in the irrigation and drainage infrastructure and bear the associated sunk-cost. This context reflects a reality where private property over the infrastructure prevails. Because in most of the cases, the irrigation systems are nested: the main systems are managed by the government, while user's groups manage the secondary and tertiary levels and individuals on the farm levels (Meinzen-Dick, 2007).

We assume *i* is a finite set with $0 \in i$ and $i \ni (0.25, 2)$ and $i \neq \varnothing$. Furthermore, we consider the following 2-stage game. In the first stage of the game, the State and the Society make the simultaneous decision of investing in the irrigation infrastructure by choosing i_1 and i_2 from *i*-set, respectively. Once the State and the Society are informed of the first stage's outcomes, they play the second stage: the Hungry Steppe Game in Table 1.

We assume that the probability of investing is greater than zero. Let us suppose that the players continue playing {*strong; weak*} so that the Society's equilibrium payoff is one. Therefore, once the State follows the same path, the Society can guarantee the payoff of 1 by choosing a strategy $(0, f_2)$ with $f_2(0) = w$. With the expression $f_2(i)$, we illustrate the Society's reaction to the *i* investment decision of the State in the first stage of the game. Similarly, with the expression $f_1(i)$, we illustrate the State's reaction to the *i* investment decision of the Society. Consequently, it turns out that any strategy $(i^* f_2)$, with $i^* \ni (0.25, 2)$ and $f_2(0) = w$ is an inferior strategy. We eliminate these inferior strategies and consider the reduced form. In this interaction now, the strategy $(0, f_1)$ with $f_1(i^*) = s$ of the State become dominated. We can consider a reduced form of the game where we eliminate all these strategies through the successive elimination of dominated strategies method. In the current game, the Society by playing $(i^* f_2^*)$ with $f_2(0) = s$ is guaranteed a payoff ($3-i^*$). However, until the relative value of *i* is less than two, none of the solutions is stable. By using the same argument, the game model establishes the instability in the equilibria solutions when both the State and the Society do not invest in the first stage, given $i^* \ni (0.25, 2)$. To achieve strategic stability, both the State and the Society need to invest in the irrigation infrastructure.

4. RESULTS

4.1. HUNGRY STEPPE PROJECT. ITS EVOLUTION THROUGH THE LENS OF COMPLEXITY AND COLLAPSE

Authors such as Matley (1970), Joffe (1995), Obertreis (2017) and Dukhovny & de Schutter (2011) describe the evolution of the Hungry Steppe project in more detail. The objective of the current work is not to repeat those authors' records but instead to reiterate the relevant major historical developments through the lens of the complexity concept.

The colonisation of Central Asia coincided with the American Civil War. As a result, Russia considered the region as a place with the potential to substitute American cotton (Beckert, 2014). However, prevailing cotton fields and Central Asian native cotton varieties were insufficient to do so. There was a need to extend the irrigated area and improve the cotton grade. While the quality issue was tackled with the introduction of American cotton, the expansion of the irrigated cotton lands was a complicated mission to accomplish for the upcoming century (Matley, 1970). The political disposition concerning cotton autonomy and the Hungry Steppe's irrigation infrastructure continued from Tsarist Russia to the Soviet government (Obertreis, 2017).

So, the problem which needed to be solved with the Hungry Steppe project was the cotton production which would substitute the import fully. At the beginning of the Hungry Steppe project implementation, the easiest, most general, most accessible, and least expensive solutions were attempted first. The Hungry Steppe canal construction, with a potential to irrigate 154000 ha (Obertreis, 2017), and the establishment of collective and State farms could be categorised as the accessible and relatively least expensive solutions. When these less costly solutions were exhausted, continued stresses due to USSR's cotton autonomy pressure required further investments in complexity.

The expansion in irrigated crop fields is associated with the corresponding scales of investments in the irrigation infrastructure. Figure 2 illustrates the total nominal state expenditures in the Soviet irrigation sector. It shows the grandiosity and its further accumulation of the sunk cost even when we consider hidden inflation rates in the country, which is well analysed by Efremov (2012).

As long as the least costly solutions were already executed, the Steppe project evolution proceeded in a more expensive direction. It constructed reservoirs, established higher education and research institutions, and built new settlements, streets, power lines, and other infrastructure along with the irrigation systems per the "integrated development approach". This all, in turn, led to increased operation and maintenance costs, which are reflected in skyrocketed O&M costs in Figure 3 from the late 1960s and onward (Dukhovny & de Schutter, 2011: 156–167; Obertreis, 2017: 284).

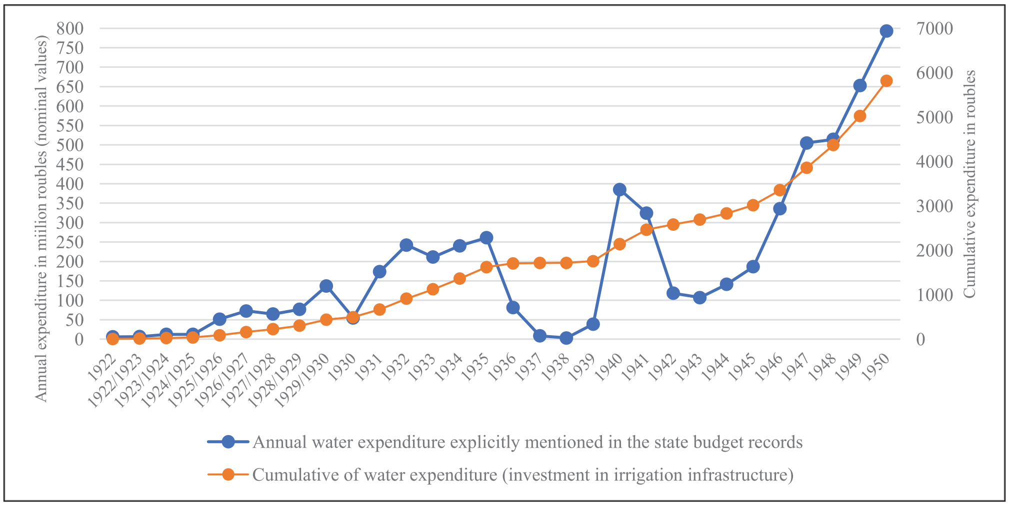

Figure 2 Soviet central state investments in irrigation infrastructure until 1950, expenditures are in nominal rouble values. Source: Istmat.info (2020).

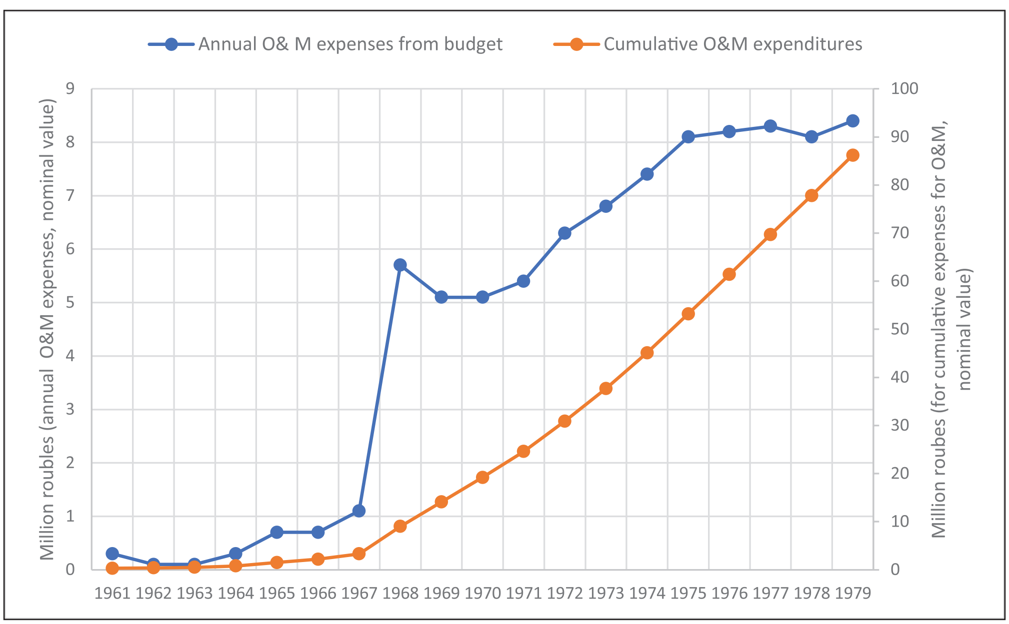

Figure 3 O&M expenses from budget: Water sector, Hungry Steppe, in nominal million roubles. Source: Dukhovny & de Schutter (2011).

We can consider the evolution path of the Hungry Steppe project as an example of a case with gradual increases in levels of complexity. The Hungry Steppe canal maintenance costs were less expensive in the beginning than the later version with reservoirs and new towns.

The benefits received from intensive cropping in the Steppe are declining since the severity and extension of salinity of Steppe soils started to increase. The empirically well-established negative causal effect of increased salinity on cotton yield and quality supports the declining benefit argument (Razzouk & Whittington, 1991).[8]

According to recent soil studies of the Hungry Steppe's Sydarya province area in Uzbekistan, although at varying degrees, all samples indicated positive degrees of salinity (Vasenev et al., 2020). Such pervasive salinity in the Steppe negatively affects the yield levels, reflected in decreased earnings from intensive cropping. Abdullaev (2004) correlates the salinity and earnings and states that, on average, per capita income in saline zones of the region is 30 per cent lower than the national income level while the unemployment level is 40% higher.

The infrastructure investments (or investment in complexity) started to decline since the 90s while preserving intensive cropping and prioritising cotton (Djanibekov et al., 2012; Veldwisch & Mollinga, 2013) which then triggered further pressure on the Steppe lands. That is, the irrigation infrastructure complexity has not been increasing since the collapse of the Soviet regime in the region, but the benefit of the existing level of complexity shifted downwards due to coupled land degradation. We can perceive this as an inward shift of the marginal product of the increasing complexity curve in Figure 1 from MP to MP*. The current Hungry Steppe project could be placed around the B2a-C2 point in Figure 1. The aspiration of further increasing investments in irrigation infrastructure in the Steppe, as the one resolution by Cabinet of Ministers of Uzbekistan No.853 initiates,[9] might be leading the Steppe project towards surpassing the B2a-C2 threshold.

According to the collapse mechanism, the collapse of the irrigated cropping system and associated complexities could be considered as a solution to the Hungry Steppe's vicious circle of intensive cropping and land degradation.

4.2. POSITIVE FEEDBACK LOOP AT PLAY IN THE STEPPE

The current paper starts with a rational theory triggered research question inquiring if the current level of investment (or aspiration to invest) in the irrigation infrastructure of the Hungry Steppe project is coherent with the conventional economic theory. The question antecedently qualified the underlying system as a negative one, though implicitly. However, the analytical part of the paper recognises the reinforcing loop as the feedback type which entrapped the Hungry Steppe in the vicious circle of land degradation. Our claim about the dominance of the positive feedback type in the present context of investment decisions explains the Steppe project's continuity even if it has been irrational for some time already as per conventional economic theory.

Intensive cropping in Hungry Steppe with a specialisation in cotton production is a *lock-in* phenomenon where the *positive feedback* mechanism is at work, and the whole process is strongly path-dependent.

One of the major sources of such *nonergodicity* is the sunk cost effect. This economic activity can be labelled as an inferior path of development or simply not the "best" option for the water-scarce Steppe communities with degraded water infrastructure coupled with salty and barren soils. Due to *random historical events* such as the American Civil War's overlap with the Tsarist colonisation of Central Asia, the Steppe was selected to replace the Californian cotton as early as the 1860s (Beckert, 2014). Afterwards, during the last 150 years, the Steppe was an object for continuous massive investments in the infrastructure. This strand of historical events accumulated and partly due to sunk cost effect locked the Steppe in the self-reinforcing loop of intensive cropping and land degradation (Figure 4).

Because of the sunk cost effect, the decision-makers are inclined to rehabilitate the infrastructure. This further exacerbates the sunk cost; it leads to further opting for the intensive cropping and further pressurising the land, enhancing the degradation process in the Steppe, and so on. It is a vicious circle.

Farmers of the region massively use the leaching technique to wash the salt from the soil surface, which raises the water tables, especially with the prevailing degraded and mostly dysfunctional drainage system in the Steppe. That is, there is a salinisation feedback at play in the Steppe as well (Kushiev et al., 2005).

Furthermore, there is a positive two-directional linkage between land degradation and the poverty level of rural inhabitants of low-income countries (Barbier & Hochard, 2018). Land degradation decreases the productivity of the soil, and hence Steppers, whose livelihood depends on intensive cropping, are vulnerable to such declines. At the same time, poverty is also seen as causal of land degradation, as claimed by Reardon &Vosti (1995).

The salinisation feedback loop and poverty-degradation vicious circle are also at play and accordingly placed in the bigger picture of the positive feedback loop of intensive cropping and land degradation (Figure 4). The prevalence of the poverty degradation loop in Figure 4 can serve as evidence that the persistent equilibrium is inferior concerning the wellbeing of the Steppe community.

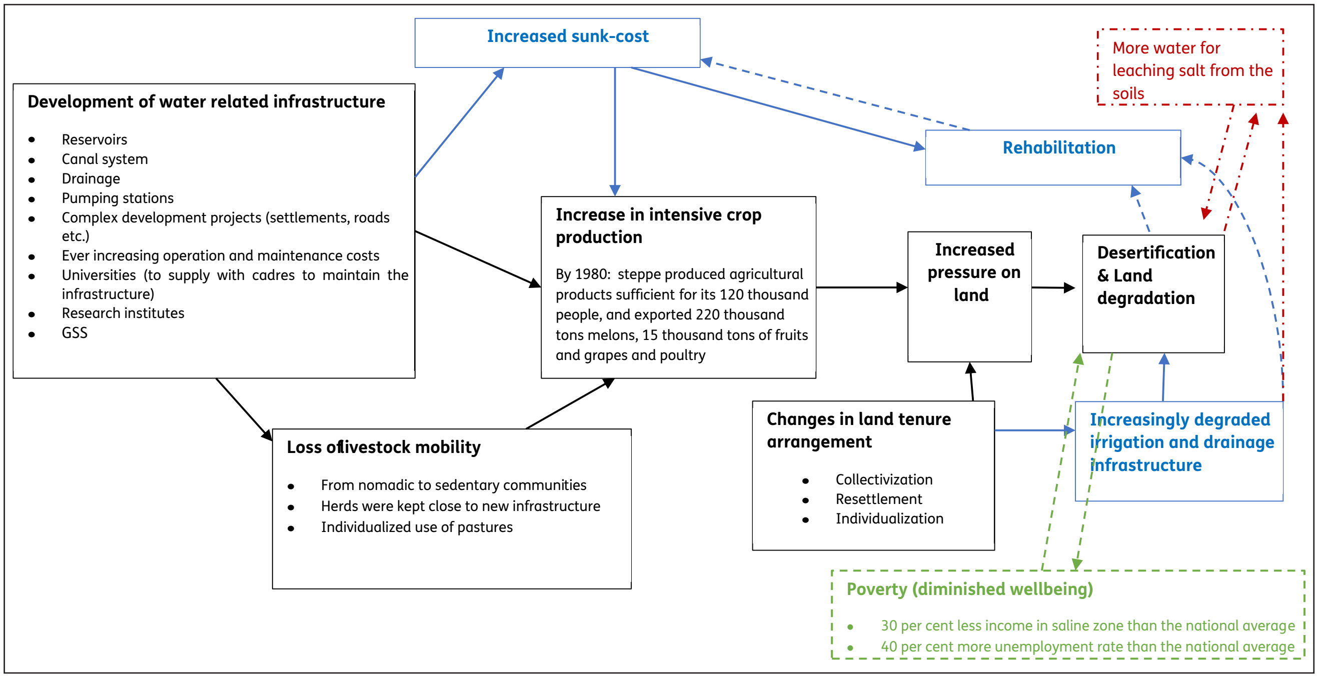

Figure 4 Recurrent societal drivers of desertification case in Hungry steppe. Positive feedback loop sourced from sunk cost effect. Source: Adapted from D'Odorico et al. (2013) to illustrate land degradation drivers using sources for Hungry Steppe as Obertreis (2017); Bucknall et al. (2003); Abdullaev et al. (2007); Alimaev & Behnke (2008), positive feedback literature as Arthur (1994), Kay (2005) and Heinmiller (2009), land degradation and poverty interlinkage literature Barbier & Hochard (2018) and Abdullaev (2004).

4.3. THE ENTIRE PERSPECTIVE: STEPPE GAME, COMPLEXITY & POSITIVE FEEDBACK LOOP

This subsection joins the pieces together and contributes to gaining the entire perspective of the analyses. Table 3 illustrates the stable solutions of the Steppe game for different values of sunk cost (*i*).[10] At the same time, the table positions the different phases of the Hungry Steppe project implementation across the set of stable solutions. The Steppe was an object for more complex solutions as part of the cotton production growth objective since its start. Accordingly, the current table classifies the sunk cost size throughout the project phases, ranging from Tsarist time to the present. In doing so, it considers the ever-growing complexity and associated costs, hence qualitatively allocates values for *i*. As illustrated in Figures 2 and 3, annual and cumulative water expenditure records serve to support the assumption about the ever-increasing sunk cost of the project in Table 3.

In most of the cases (with varied *i* values), the interactions are subject to multiple equilibria. The reflection in the reality column provides some historical comments, which serve as evidence supporting the prevalence of one or another stable solution during a particular phase of the project.

Let us derive key messages from Table 3. First, with more years, the complexity of the project and hence associated (sunk) costs kept culminating. And hence the stable solutions of the Steppe were not all the same throughout the 150 years. State and Society tandem were entrapped in one or another equilibrium. The cases when State was investing, even if it was not the equilibrium or when there was no investing stable solution as well, could be accordingly interpreted as per the Soviet ideological aspects as the drivers of large projects implemented in the USSR (as explained in Kelly et al., 1983; Josephson, 1995)

Second, mostly the State does not invest in the infrastructure, but it nevertheless achieves its preferred outcome with intensive irrigated crop production when the institutional framework allows the only State to invest in the irrigation infrastructure (Scenario A, section 3.2). Because all qualitative values of sunk cost (*i*) in Table 3 are associated with one particular stable solution where the State does not invest and behaves strongly and attains intensive cropping. This stability holds due to decision making under sunk cost effect. Consequently, the sunk cost role in the positive feedback loop (as in Figure 4) is vindicated.

When, however, the institutional setting allows both State and Society to invest, e.g., when private water market arrangements prevail, both parties' investment is a possible, stable solution (Scenario B).[11] Among the significant qualities of private property in water management is that it creates a sustainable investment mechanism for resource users (Rosegrant & Binswanger, 1994). In theory, the region's farmers could have a practical and viable solution for the

PROJECT PHASE	CONDITIONAL VALUE OF	THE STABLE SOLUTION(S)	THEORETICAL JUSTIFICATION[a]	REFLECTION IN REALITY[b]
Tsarist Russia	$0 < i < 0.25$	*{Doesn't & strong; weak}*	State gets maximum payoff; Society cannot signal a deviation	
		{Invest & weak; strong}	State wins from investing hence invests. It behaves weakly because deviation by State cannot be an unambiguous meaning.	• **(Confirm)** Start of Hungry Steppe project. • The total investment of Tsarist Russia in the Hungry Steppe amounted to around 126 million in current USD
Early Soviet years	$0.25 < i < 2$	*{Doesn't & strong; weak}*	Only one outcome survives the iterative elimination of dominated strategies. The State does not invest, but it gets its most preferred equilibrium. The availability of an additional subgame, even if not used, has significant consequences.	• **(Confirm)** By the 1930s, only trivial actions had been taken in the irrigation infrastructure expansion in the Steppe. • **(Contradict)** However, several big *sovkhozes* were established; By the year 1938, there was 154,000 ha of arable areas along the canal. Cotton -the primary crop.
Post 1950s	$2 < i < 2.25$	*{Invest & strong; weak}*	After State invests, Society responds by being weak, as the other alternative is dominated strategy and hence eliminated (not chosen). Intuitively stable. By investing (choosing a particular subgame), the State signals the Society own intentions, and the Society has no other option but to choose to be weak	• **(Confirm)** More investments. • The State constructed three reservoirs from 1943-to 1965. • The complex development approach started. • From 1950s, the project's cost included dams, pumping stations, main canals, and drainage networks. • Maintenance of complex development approach with its new towns and economic activities. • Cotton - the priority crop.
		{Doesn't & strong; weak} *{Doesn't & weak; strong}*	Because Society never knows whether the State will continue as strong or weak if it does not invest. Singletons.	• (**Confirm** for late Soviet years) Construction and effective use of drainages remained neglected; it lowered the cotton yields and triggered even more water use, leading to higher salinisation. • Cotton - the priority crop
1990s–present	$i > 2.25$	*{Doesn't & strong; weak}*	Both strategies coupled to investment is dominated by the *maxmin* strategy so that additional option is entirely irrelevant, and the game reduces to the one in Table 1 (Steppe Game, i.e., Battle of Sexes)	• **(Confirm)** Little maintenance has been conducted on the drainage networks; • ~90% of the vertical drainage systems are unused because of the costly pumping stations • Cotton – prioritised crop. • The average cost of the irrigation development project was about USD18,000/ha. • **(Contradict)** initiatives from the State to invest in Hungry Steppe irrigation infrastructure;
		{Doesn't & weak; strong}		

Table 3 Possible values of and associated stable solutions. Positioning of the Hungry Steppe project across set of stable solutions. Scenario A. Source: [a] Adapted from Van Damme (1989); [b] Matley (1970); Joffe (1995); Dukhovny & de Schutter (2011); Bucknall et al. (2003); Obertreis (2017); Amirova (2019).

emerged problems, including deteriorated physical capital and water disputes, if the market mechanism prevails for the water sector (Amirova, 2019: 89–119). Investment under Scenario B becomes a strategic stability guaranteeing option, given $0.25 < i < 2$. With other qualitative values of i while there are several stable equilibria, the investment strategy also became best response.

Scenario B's circumstances will perpetuate economic activities within the positive feedback loop of intensive cropping and land degradation. However, the degrading consequences could be less alarming than the ones stemmed from Scenario A because of relatively proper irrigation and drainage infrastructure.

4.4. OPTIONS OUT

Both scenarios are locking Steppe into the intensive cropping and increasing land degradation. Therefore, the current paper proposes the collapse of irrigation infrastructure as the solution for the resource dilapidation lock-in phenomenon in Steppe, which is also locked in the poverty trap. Without any transition strategies and programs, however, such a collapse could negatively affect the wellbeing of local dwellers. This subsection provokes the discourse on some of the non-mutually exclusive alternatives to intensive cropping in the Steppe.

One such state program is voluntary resettlement programs. In this regard, the country can derive lessons from similar practices elsewhere. For example, Ethiopia launched the Voluntary Villagization Scheme when faced with overcrowded and resource deficit areas and resultant difficulties (Zeleke & Mberengwa, 2012). If the government undertakes this type of resettlement program, it must ensure that it engages with international processes. It should avoid any involuntary resettlements, which was the case in the very Hungry Steppe a hundred years ago (Obertreis, 2017: 277–278) or other contemporary cases with negative consequences mentioned above, e.g., Ethiopia (Wayessa & Nygren 2016).

The rural non-farm economy has gained prominence in rural development's general debates (Start, 2001). In developing a non-farm economy in the Steppe, the State will need to launch labour adjustment facilitating programs, non-farm business financing credit lines (Gale Johnson, 2002).

Moreover, the State can finance the Steppers with direct payments. However, there is a risk of ending up with a community that entirely lives on those payments (Bucknall et al., 2003).

Establishing a transhumant herding system in the Steppe could be another simultaneous program. However, it requires a proper coordination mechanism for sustainable pasture governance. In a legal grey zone, Uzbekistan practices the individual forms of pasture land use (Robinson et al., 2012). Degrading the environmental impacts of private property rights on pastures is evident from empirical studies (Galvin et al., 2008). The legal settings enabling better livestock mobility could be a long-term solution to pasture overgrazing. Nomadic pastoralists' history of the region might offer specific lessons which can facilitate wellbeing and sustainability enhancing solutions (Robinson et al., 2012).

The current paper's discourse on options-out is in line with Varis (2014), who calls the former Soviet Central Asia as a whole for economic reform to ease environmental and social tensions.

5. DISCUSSIONS & CONCLUSIONS

Globally drylands occupy 41% of Earth's land surface, up to 20% of which is degraded and directly affect around 250 million people in the developing world (MEA, 2005). Hungry Steppe is one of such degraded drylands. Hungry Steppe is a part of the Northern Eurasian dryland belt (Groisman et al., 2018). This implies the relevance of the current paper's analyses and its arguments to other degraded steppes of the world.

This paper scrutinises the Hungry Steppe's evolution as a project for 150 years and points on the continuously increased complexity as a solution to the State's cotton production mission. The study aims to understand the reasons behind the ongoing investment projects and aspirations to invest in the Steppe's irrigation infrastructure even when the conventional economic rationale is worthless. According to our analyses, continuous investment in complexity contributing to the Steppe's lock-in in the intensive cropping and land degradation loop through the sunk cost source of positive feedback mechanism can explain the reason behind the investments and aspirations to invest further in the project.

To ever-increasing cotton production stress due to Tsarist and then Soviet cotton autonomy ideology, the State responded by increasing complexity level in the Steppe. In this way, the government kept increasing investments in irrigation infrastructure, agriculture and its organisation, education and specialised training, resettlement, service sector, construction of towns, infrastructure maintenance and rehabilitation and etc. (Dukhovny & de Schutter, 2011).

During the last century, like the dryland belt, the Hungry Steppe faced land-use change, rapid institutional shifts, climatic changes, and natural disturbances (Kushiev et al., 2005; Djanibekov et al., 2012; Mirzabaev, 2013; Obertreis, 2017; Cameron, 2018). Groisman et al. (2018) state that "these factors intertwine, overlap, and sometimes mitigate, but can sometimes feedback upon each other to exacerbate their synergistic and cumulative effects". Such feedback cumulatively affecting the degradation further is accordingly illustrated in Figure 4. It describes the recurrent societal drivers of desertification and consequently applies the Hungry Steppe case to the scheme. By introducing the sunk cost element resulting from investments in complexity, the scheme pronounces the existence of a positive feedback effect. Doing so explains the logic of the claim about the Hungry Steppe lock-in phenomenon.

The paper employs game-theoretic modelling to give more legitimacy to the role of sunk cost effect in this lock-in. The modelling analyses illustrated how sunk cost effect contributes to the prevalence of positive feedback in the case of Hungry Steppe. In turn, positive feedback helps explain how the bureaucratic institution locks the Steppe into the intensive cropping and land degradation loop with deteriorated infrastructure in the contemporary Hungry Steppe. This approach helps to understand the mechanisms at play in the Steppe project dynamics. It goes beyond the claims that Soviet ideology is the sole driver of big irrigation infrastructure described by scholars (e.g., Kelly et al., 1983; Josephson, 1995). However, there are moments where the modelling cannot interpret the existence of some realities against the stable equilibria alternatives (Table 3), where the suspicion still lies in the Soviet ideology.

Furthermore, by altering the institutional setting and making the Steppe's resource users the owners, the analyses conjecture that the Steppe's problem with underinvested infrastructure could be resolved.

It is worth mentioning that the Scenario with a private property regime is a better alternative than the status quo, where the State incurs the investment in the infrastructure due to the specificities of the prevailing property regimes. This finding aligns with global literature findings that claim that private property (or at least some of the significant bundles of it) in the water sector entails many benefits (Meinzen-Dick, 2014).

Yet both scenarios entrap the Steppe in the intensive cropping and land degradation positive feedback loop. Hence intensive cropping's collapse could be a solution to such an inferior lock-in phenomenon.

So that the collapse of the complex system of irrigated agriculture in the Steppe does not degrade already impoverished livelihoods, several transition programs should be initiated. Accordingly, the paper proposes a non-mutually exclusive and non-exhaustive list of alternatives or transition solutions: non-farm job creation, voluntary resettlement programs, direct payments, and a transhumant herding system.

Following Nosek et al. (2018), current work can be categorised as a "postdiction" research, as it uses existing (historical) observations of the irrigation development project in the Hungry Steppe to generate ideas about how the world of decision making took place in this context. By using feedback mechanism, complexity/collapse concept and game theory approach in the analyses, the current work proposes hypotheses to be further researched and tested. The study helps the reader to get more conceivable insights into how investment decision making took place concerning the Hungry Steppe and how it locked the Steppe in the vicious circle of land degradation. The next step is to test whether the postdiction narrative the paper propels is a reasonable explanation using new observations if possible.

Below are the major (or most interesting to the author's subjective view) hypotheses current work's postdiction generates for further research:

1. Hungry Steppe Project of irrigation agriculture-based system already started the process of collapse as per Tainter's definition of the term.
2. Although preferable over the state mechanism, the market mechanism over the irrigation infrastructure does not break the vicious circle of land degradation persistent in the Steppe.
3. Alternative options for livelihoods (as suggested in the paper) in Hungry Steppe are wellbeing enhancing and feasible due to best response play.

There will be a strand of decisions to make in the coming years against the background of ever-dilapidating land and water resources for a Hungry Stepper or any other dweller of a similarly depleted dryland zone. Should one migrate, as there is almost no chance to find a job in the non-farm sector? Should one launch a local non-farm business, how to finance the plan? Should one give up on farming? Should they collaborate and convert degraded lands into pasturelands and shift to foraging? These are not easy decisions to make. Later or sooner, several hundred thousand people might be forced to make similar decisions. There is an immediate need for economic reforms addressing the above matters to appease the current and prospective environmental and social tensions in the Steppe.

NOTES

1 "In postdiction, the data are already known and the postdiction is generated to explain why they occurred. … Generating postdictions is vital for discovery of possibilities not yet considered" (Nosek et al. 2018: pp2600–2601; more on differences of postdiction from prediction see Nosek et al. 2018).

2 Following Tainter (1988) the discussion will most often refer to "marginal return". "This may be taken to mean the same thing as marginal product, that is, return per increased unit of investment. The word 'return' is preferred to 'product' to emphasize the concern with whatever benefits a population obtains from its investment in complexity" (p93).

3 In this context, the term "complexity" (or "simplicity") is referred to the infrastructural solutions of the production objectives. Mobile herding society does not invest much in complex infrastructure, while the sedentary farming society has no option but invest more in complex infrastructure.

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