Modeling Sustainability Scenarios of Renewable Natural Resources and Economic Growth using System Dynamics

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Abstract

This paper presents a theoretical model of the relationship between Renewable Natural Resources (RNR), local economy and industrial economy. Through system dynamics modelling, this study tests the impact of three policy interventions, 1) Resource efficiency, 2) Resource efficiency and green growth and 3) Localisation of economy, on RNR and the economy. The base case simulation indicates overshoot and collapse of economy due to resource depletion. Resource efficiency and green growth policies are successful in delaying the overshoot and decline of the economy but fail to offer economic recovery. Localization of economy increases the economy's responsiveness to depletion of the natural resource stock, thereby enabling it to avoid the economic overshoot and decline within the simulation time. In the extended time scenario the local economy also goes into an overshoot and decline but it manages recovery resulting into long term oscillations. Through these scenarios the paper highlights the need for economy to be proactively responsive towards changes in levels of stock of RNR rather than flows (i.e. supply) in order to avoid an overshoot and fall. The paper concludes by making a case for promotion of slow growth local economies as a strategy to enable transition towards long term ecological-economic equilibrium.

Key Words: Green Growth, Resource Efficiency, Renewable Natural Resources, System Dynamics, Economic Localisation

Introduction

Since the Industrial Revolution, economic growth, dependent on production, exchange and consumption of economic goods, measured in terms of the Gross Domestic Product (GDP) of the economy, has benefited by appropriating heavily from the natural resource base (Krausmann et al, 2009). Increased access to fossil fuels and technological advancements have consistently allowed for greater extraction of natural resources for conversion to economic goods.

However, as illustrated by the Millennium Ecosystem Assessment 2005 (MEA, 2005), this rapid consumption of natural resources over the past 50 years has resulted in considerable, and to a large extent, irreversible loss of ecological diversity. These largely irreversible losses of biological diversity are a result of short-sighted, unplanned and mismanaged natural resource extraction. Exceeding rates of extraction beyond sustainable yields for renewable natural resources can result in non-linear, often rapidly declining and sometimes irreversible loss of resources (MEA, 2005). This disregard for resource regeneration dynamics poses a clear threat to the sustenance of the human kind and economy (Hoffman, 2010).

The problem of overexploitation and exhaustion of resources could also be seen as the inevitable consequence of conflict between the human paradigm for economic growth and the need to sustain the flow of resources (Hoffman & Ireland, 2013). Unless the common-pool resource is very abundant, the outcome will be high subtractability, leading to severe resource depletion and ultimately resource exhaustion (Hoffman & Ireland, 2013). Therefore it is necessary to relate sustainable resource use with economic management strategies. Sustainability of economic growth in a finite resource environment has long been questioned and acknowledged as a complex issue (Forrester 1971; Meadows et al. 1972; Meadows et al. 1974). Given that the economic system is embedded in the ecological system in terms of resource dependence (Haberi et al, 2006), the sustainability of the economic system depends upon the structural relationship between renewable natural resources and how the economy consumes them for its growth (Mathur & Agarwal, 2015). The scale and design of the economy, which includes its rate of growth, intensity of resource consumption and the integration of the local and industrial economies, plays a central role in determining overall sustainability of resources and the economy itself.

Research Objective

Continuous growth of economy through production of goods results in the increase of flow of resources from the ecological to the economic spheres. This results in the depletion of finite stock of natural resources. In this paper we specifically seek to understand the dynamics of renewable natural resources and economic sustainability. Given that non-renewable natural resources can only deplete, their appropriation for human society represents dynamics distinct from that of RNR. Through the use of System Dynamics (SD) we intend to capture the non-linearities and understand the structural relationships between economic growth and RNR, which determines the overall behaviour of the consumption patterns over time. Which policies are most effective in avoiding the overshoot and fall of economy while maintaining sustainable levels of RNR.

Paper Description

This paper presents a theoretical model of the relationship between RNR, local economy and industrial economy. Through SD modelling, this study shows the interaction of the economic system with the renewable natural resource stock.

Through different scenarios, this paper highlights the impact different policy interventions have on renewable resources and the economy. The paper tests the impact of three policy interventions 1) resource efficiency, 2) resource efficiency and green growth, and 3) localization of economies. This work builds on the earlier work done for testing economic policies for sustainability of renewable resources using system dynamics (Mathur & Agarwal, 2015). For the purpose of this paper Resource efficiency is defined as improvement in the amount of resources being consumed per unit of economic output. Green growth is defined as the conscious choice of economy to improve regeneration of renewable resources in addition to resource efficiency. Localization of economies is defined as a local economy functioning as a closed system where 99% of the money flows within the local economy. In this case, the industrial economy becomes dysfunctional.

The simulation outcomes indicate that resource efficiency and green growth policies are successful in delaying the overshoot and decline of the economy but fail to offer economic recovery after the decline. Localization increases the economy's responsiveness to depletion of the natural resource stock, thereby enabling it to avoid the economic overshoot and decline in the simulation time. In the extended time scenario the local economy also goes into an overshoot and decline but it manages recovery resulting into long term oscillations. Through these scenarios the paper highlights the need for economy to be proactively responsive towards changes in levels of stock of RNR in order to avoid an overshoot and fall of the economy due to irreversible decline in renewable resource stocks.

The paper concludes by making a case for promotion of slow growth local economies as a strategy to enable transition towards ecological and economic equilibrium. This equilibrium is envisaged as a state of dynamic balance between the stocks of economy and ecology achieved through a set of decision rules which govern the consumption flows in a manner which does not lead to a breach of the tipping points of RNR stocks. Finally, it touches upon the importance of conscious temporary degrowth in order to allow renewable resources to regenerate, and emphasizes on the need for further empirical research in this field.

Framework and Model Description

Research Methodology

System Dynamics

Given the complexity involved in the interactions between economy and resources, the problem of management of resources must be seen through the lens of complex systems. Such complex systems may be best understood using dynamic simulation techniques. Long-term simulations of the relationship between economy and resources could provide useful insights about the binding constraints of resources (Hoffman, 2010).

System dynamics is an approach best suited to study nonlinear complex systems over time using stocks and flows, internal feedback loops, and time delays (MIT, 1997). The methodology was conceived in the 1950s at the Massachusetts Institute of Technology (MIT) by Jay Forrester (Forrester, 1961). SD as a modelling discipline holds the potential to unveil the impish nature of complex systems and uncover the relationships between variables which are responsible for the behaviour of the system. It is that branch of control theory which deals with socio economic systems and that branch of management science which deals with problems of controllability. (Coyle, 1977) Compared to traditional methods, this type of simulation approach studies the dynamic, evolving, cause-effect interrelations, and information feedbacks that direct interactions in a system over time, and it does not always require long time series data. System dynamics is usually characterized as a ‘‘strategy and policy laboratory’’ and ‘‘socioeconomic system laboratory'' because it provides a tool to test the effects of various strategies and policies in a system (Wei et al., 2012). Its applications have been in various fields, such as in ecological economics by Uehara (2012), Uehara et al. (2012), resource feedback dynamics by Moxnes (2004, 2010), environment and resource modelling by Dacko (2010), Ford (2009), modelling urban carrying capacity and quality of life by Mathur & Sharma (2015), assessment of the sustainability of a city by Tsolakis et al. (2015), integrating economic, human, social, natural capitals to assess the sustainability and quality of life by Beck (2012), environmental problems that exist in urban system structures by Akhmad Hidayatno (2012) and land resources Cheng et al. (1999), etc.

Dynamic Hypothesis

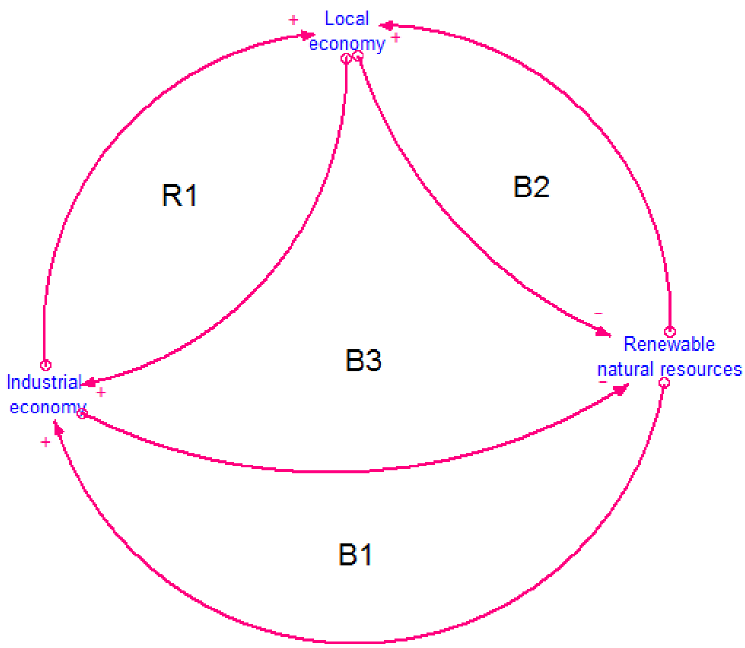


Figure 1 Dynamic Hypothesis

The model consists of three sectors, 1) Industrial economy, 2) Local economy and 3) Renewable Natural resources. The hypothesis is that both economies depend on use of renewable natural resources for their economic activities. Industrial economy and local economy exchange goods and services thereby positively reinforcing each other's economic growth. As both economies consume renewable natural resources, the stock depletes over time. This depletion leads to reduction in the flow of resources extracted by both economies for their consumption. Although there is a delay, through this feedback the RNR put constraints on the growth of the economies thereby functioning like the carrying capacity. The reinforcing loop between local and industrial economy when dominant leads to high economic growth and depletion of resources.

Model Description

The model structure and parameters used in this study are intended to set up a model environment where simulations can be used to test assumptions and policy implications. The model has been simulated for 300 years to capture the delayed feedbacks and its long term impacts on the economy and resources.

Model Boundaries

1) The economies (industrial and local) are considered to be a closed system, similar to the world economy.
2) The dynamics of money creation is considered outside the scope of the model
3) Renewable resources include open access resources from provisional ecosystem services (eg. Forest, ground water, fisheries etc.). All other ecosystem services are considered outside the scope of the model.

Sector Description

The model consists of three sub systems — Renewable Natural Resources, Local Economy and Industrial Economy[1].

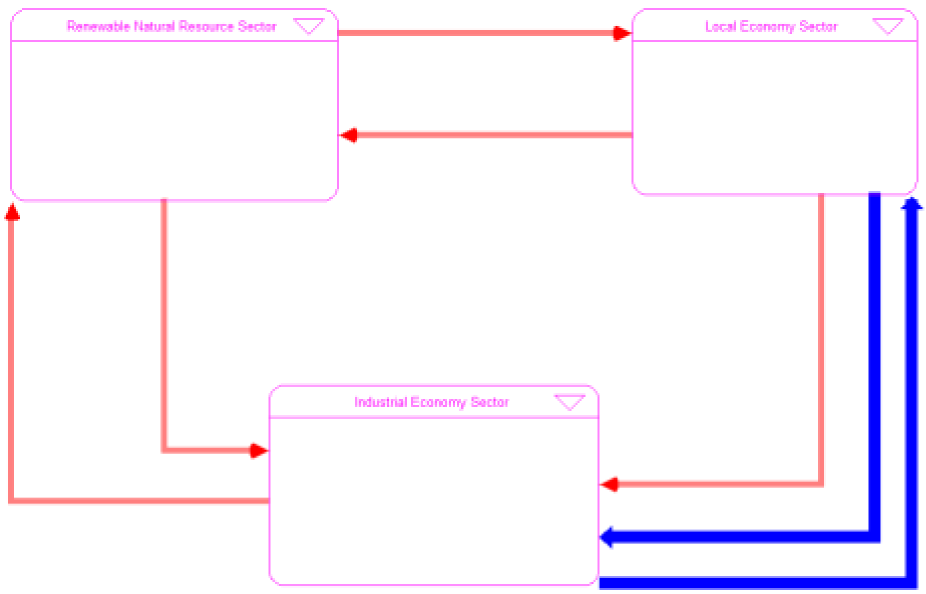


Figure 2 Sectorial Linkages

Renewable Resources

The renewable natural resource stock is taken as a reservoir of open access renewable resources (eg. forests, groundwater, fisheries etc.). Following (Brander & Taylor, 1998), the regeneration of renewable natural resources is defined by the equation

$$\frac{dS}{dt} = r(S - T)(1 - \frac{S}{K})$$

Where,

r is the intrinsic growth (or regeneration) rate,

S is the stock of renewable natural resources,

T is tipping point,

[1] Complete model structure, equations, parameter values, and description of each variable are provided in the Supplementary Material

K is the carrying capacity of the stock

The initial value of S is assumed to be 10,000 kilograms, K is 20,000 kilograms, and T is 2,500 kilograms. The regeneration rate, r, is kept at 4% per annum (Brander & Taylor 1998). Renewable natural resources are shared between industrial economy and local economy according to the size and growth of their economies. There is no privatisation of these resources. Renewable resources have a regeneration rate and also a tipping point which if crossed, reduces the resource's ability to regenerate. Growth rates of economy, its size and resource consumption intensity drive the resource consumption flows.

A maximum possible extraction fraction is kept at 10% of the level of the stock. This fraction implies that some stock of resources will be left either because they were too difficult to extract or they had become economically unviable.

The renewable resources create a feedback on the industrial and local economy due to their depletion. The local economy gets impacted if the stock levels deplete while industrial economy gets impacted if the extraction flows are unable to keep up with demand.

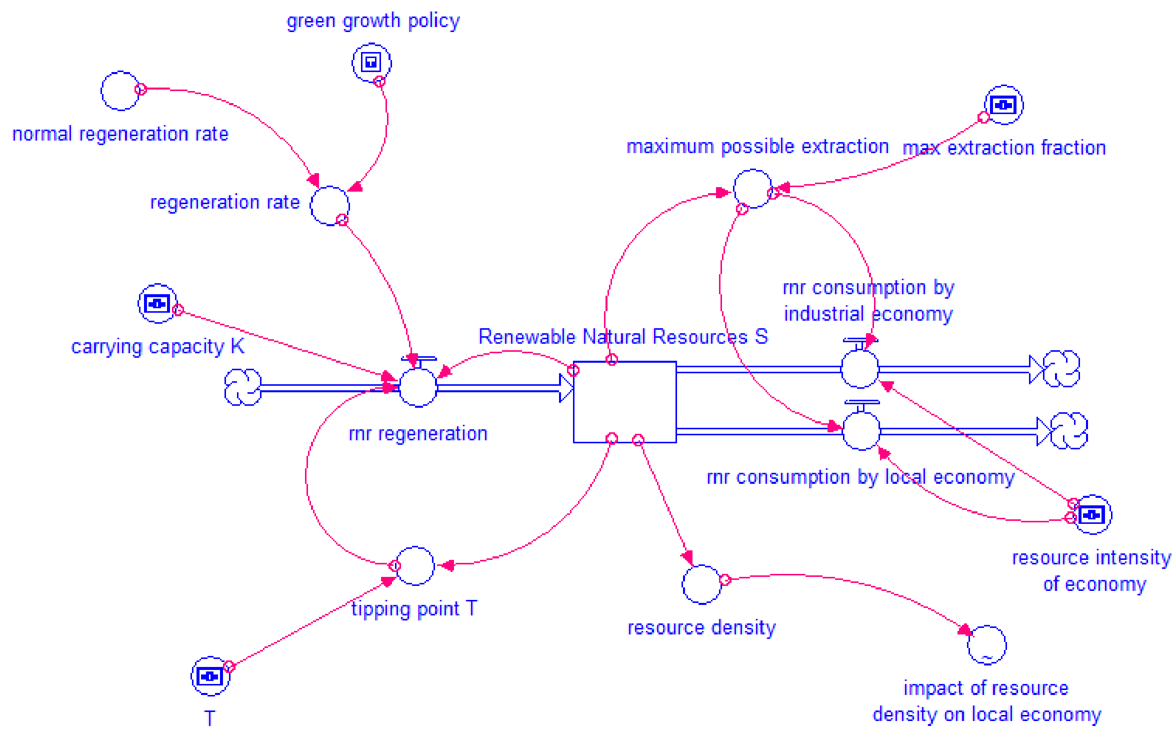


Figure 3 Renewable Natural Resources Sector Diagram

Local Economy

The local economy sector comprises of two stocks – cash with households and cash with local cottage industries, both measured in Indian Rupee (INR). Initial levels of both the stocks are kept at INR 10. The rate of money flow (shown as spending fraction) is considered to be 100% and the stocks of cash act like savings. The wealth from households flows to cottage industry in form of spending for purchase of goods while the cash with cottage industry is utilized as payments to local households for their labour, thus completing the circular flow of the economy.

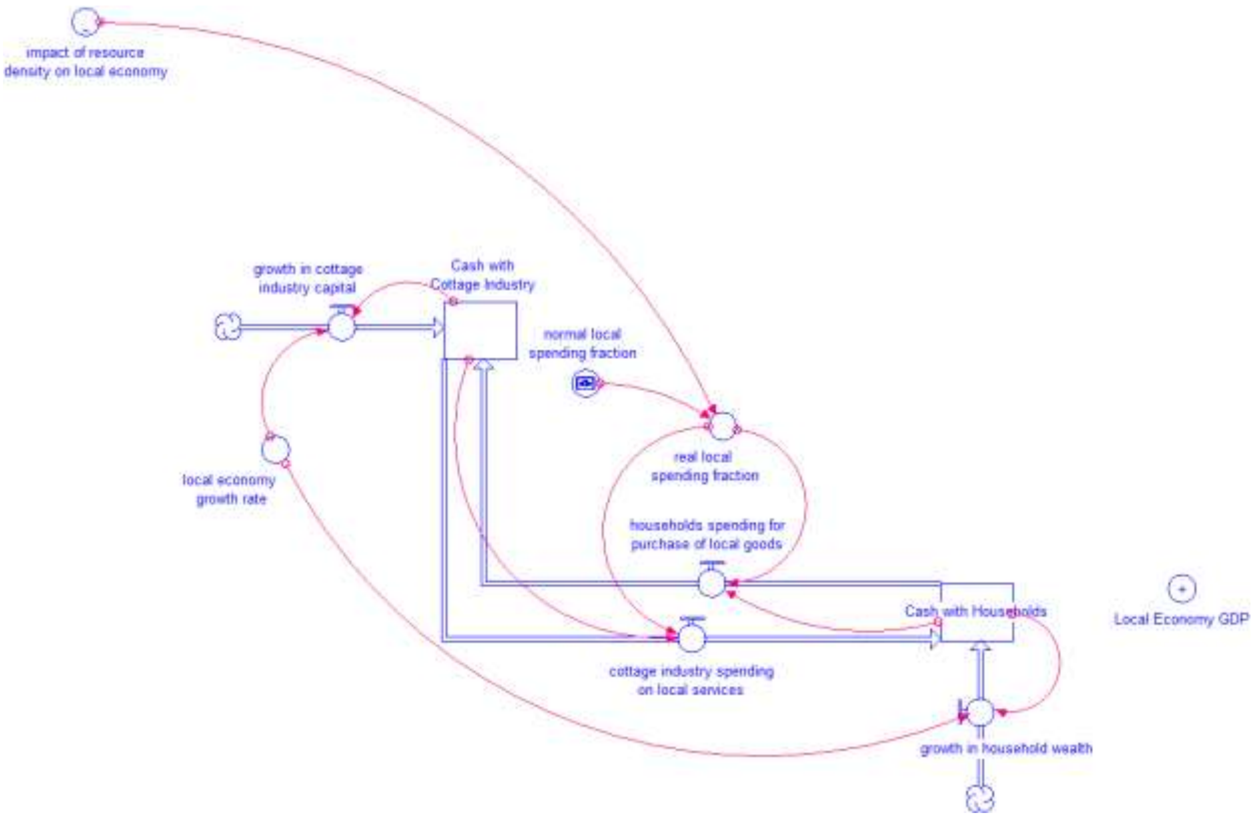


Figure 4 Local Economy Sector Diagram

The local economy is conceptualized as a smaller, traditional economy with higher information symmetry between the producers and consumers. Local economies are assumed to be inherently slower in growth than industrialized economies due to their dependence on local forms of livelihoods. Its growth rate is kept at 2% per annum. The livelihoods in the local economy mainly rely on human skillsets and depend on natural resources as input for production. Moreover, since livelihoods in the local economy have direct dependency on renewable resources they are highly responsive to the changes in the levels of resource stocks. This is modelled as feedback from falling density of resources to local spending in local economy.

Industrial Economy

By contrast to the local economy, the industrial economy represents industrialized form of production of goods. It comprises of one stock, cash with industries, measured in INR. Its initial value is kept at INR 10. Following the five stages of economic growth and development (Rostow

1959), the growth rate of the industrial economy follows a bell-shaped curve over the simulation period. It starts with 1%, reaches a maximum of 7%, and falls back to 1%.

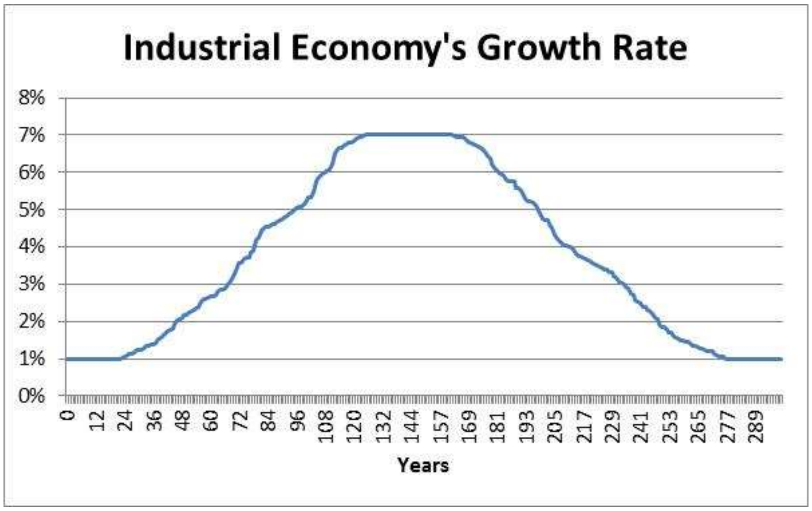


Figure 5 Industrial Economy's Growth Rate

The total value of the produce of both the local and industrial economies, much akin to a nation's GDP, is calculated as sum of the flows of payment for purchase of goods and growth of the economy. Moreover, it is assumed that the economy is a closed system, its only interaction being that with the natural resource stock.

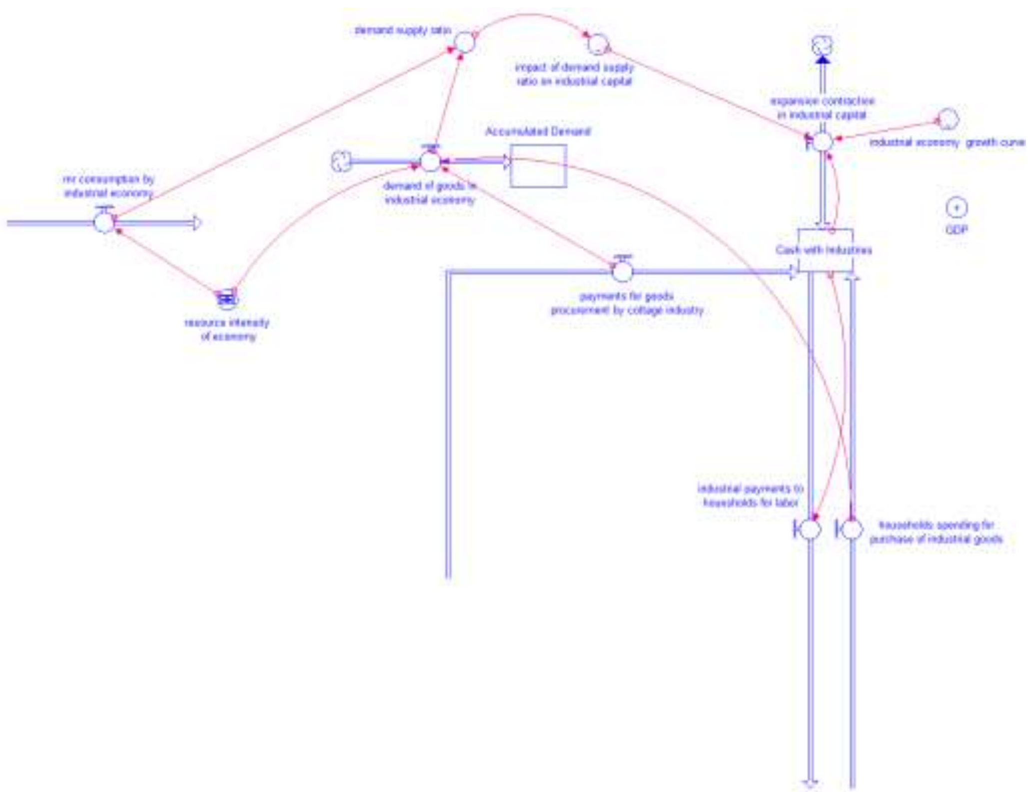


Figure 6 Industrial Economy Diagram

Integration and Isolation of Economies

The Local Economy and the Industrial Economy interact through money flowing between them.

If the local economy is completely closed, then there is zero money flowing between industrial economy and local economy. This scenario is conceptualized as localized economy relying on local exchange of goods. All the money flow occurs locally. While if the local economy is not completely closed then the households also buy goods from the industrial economy, while the local cottage industry procures goods from industrial economy and acts like a reseller apart from having their own production.

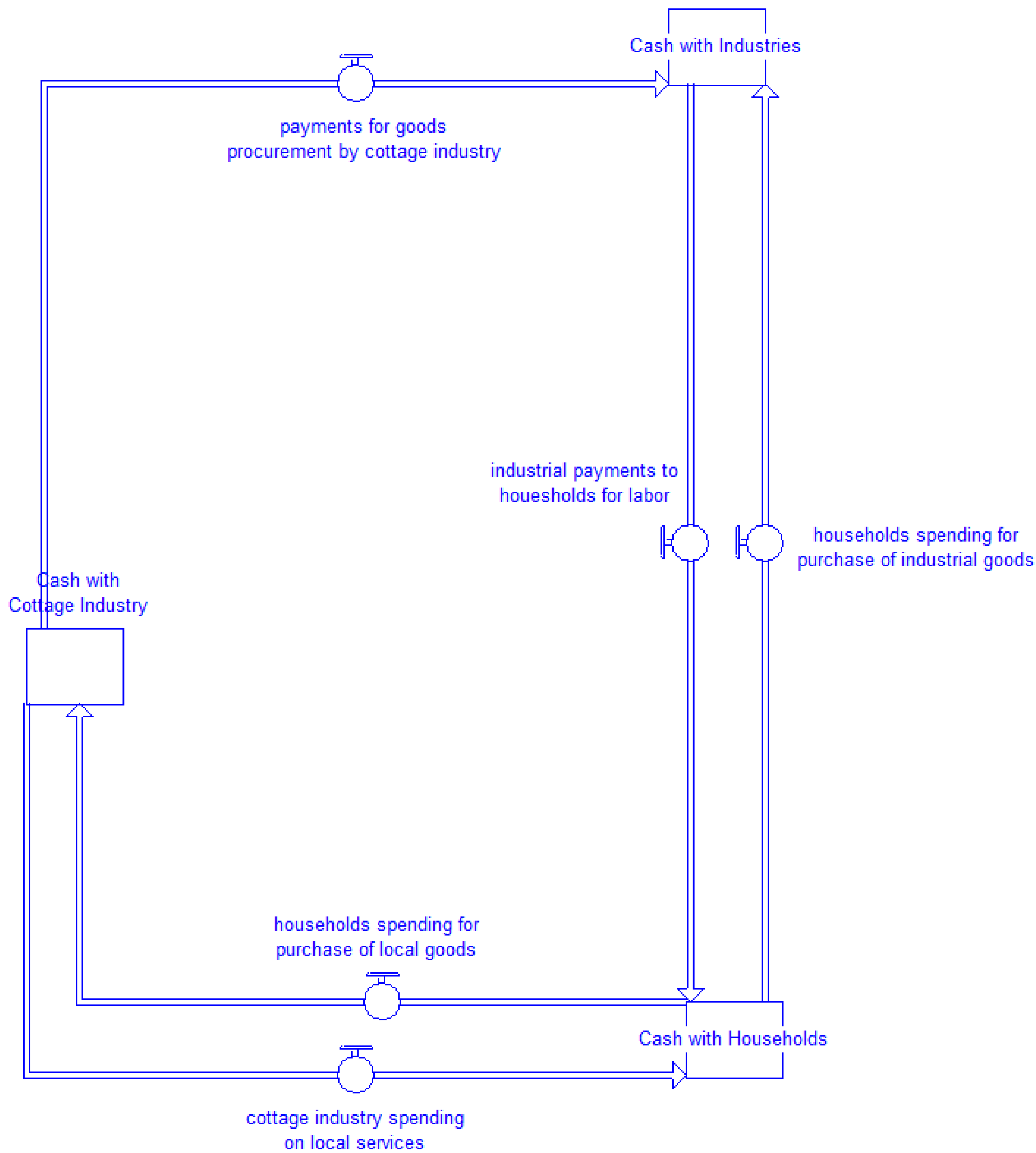


Figure 7 Interaction between Industrial and Local Economy

Resource Intensity of Economy

Resource intensity is an exogenous variable in the model, measuring the efficiency of resource use in the economy. It is measured as kilograms of resources consumed per unit of economic output. Its initial value is kept at 1 kg/INR. Resource intensity of economy is assumed to be same for industrial and local economy.

Green Growth

Green growth is an exogenous variable in the model, which impacts the regeneration rate of renewable natural resources. It is given as a policy switch which if checked would increase the regeneration rate of renewable natural resources by 50%.

All parameter values in the model are assumed, as it is a theoretical model. Their sensitivity runs and extreme condition tests are given in the supplementary material.

Graphical functions and key feedback relationships

1) **Impact of ratio between resource extraction and resource demand on inflation in industrial economy:** The feedback from renewable natural resources to industrial economy is modelled as a feedback from the ratio of demand to supply of resources which impacts the inflation. Higher this ratio higher would be the impact on inflation due to high unmet demand. Once the ratio reaches 3, which implies very high inflation, the demand corrects. This is shown through a fall in inflationary pressure which becomes negative and leads to contraction in the economy. The inflationary pressure creates a feedback on the industrial economy by impacting its rate of expansion or contraction. High inflation would imply falling value of money which means further expansion in the economy and vice versa (Mathur & Agarwal, 2015).

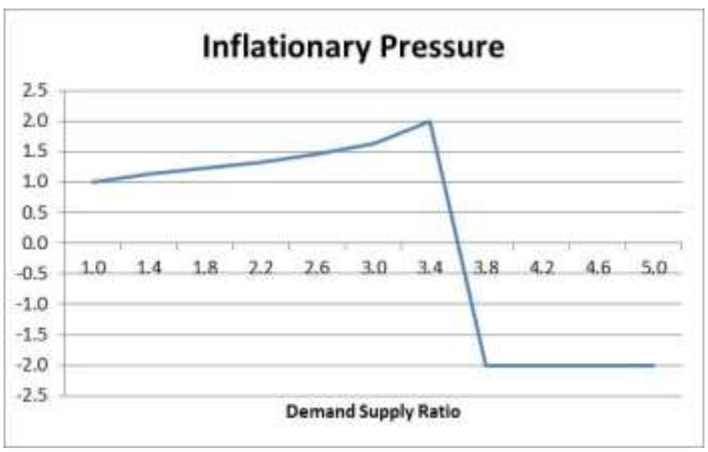


Figure 8 Inflationay Pressure due to Demand Supply Ratio

2) **Impact of density of renewable natural resources on local economy's spending fraction:** The feedback from renewable natural resources to local economy is modelled as a feedback from the level of stock of renewable natural resources to the local spending fraction. As the natural resource base shrinks the production and consumption of goods in the local economy falls due to reduced availability of natural resources for local livelihoods. It is to be noted that whereas the feedback in the local economy comes

directly from the changing levels of stock of RNR, by contrast in the industrial economy it only comes from an indirect variable, i.e. the inflationary pressure due to reduction in flow of RNR. This makes the feedback of RNR on local economy faster as compared to industrial economy.

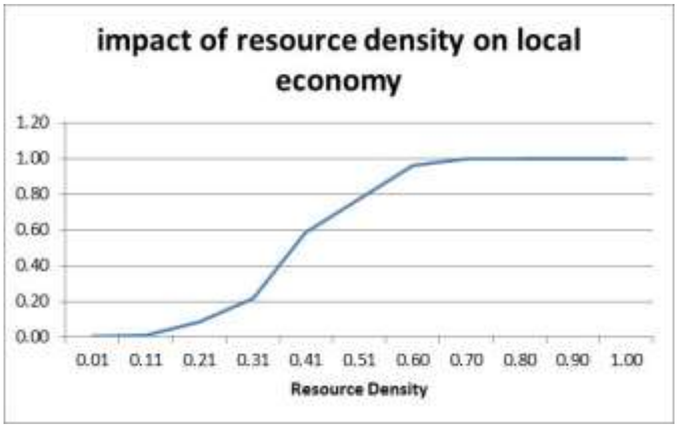


Figure 9 Feedback from Natural Resources to Local Economy

3) Impact of level of Stock of renewable natural resources on its regeneration flow (ref. to equation explaination in the earlier section)

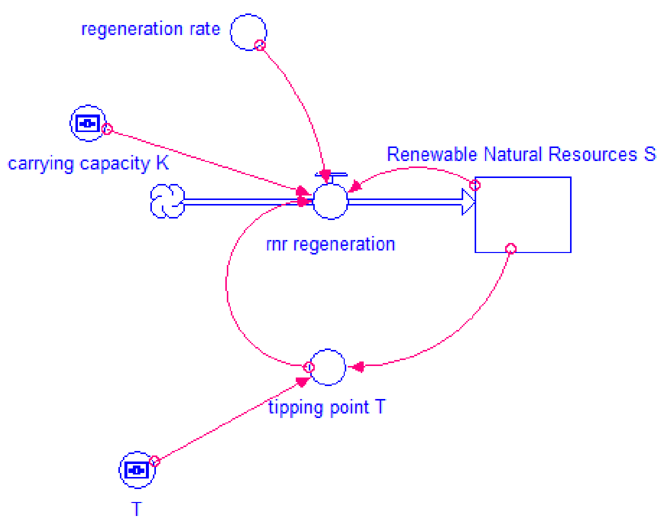


Figure 10 Natural Resource Carrying Capacity Diagram

Where,

Regeneration rate is the intrinsic growth rate of RNR

S is the stock of renewable natural resources,

T is tipping point,

K is the carrying capacity of the stock

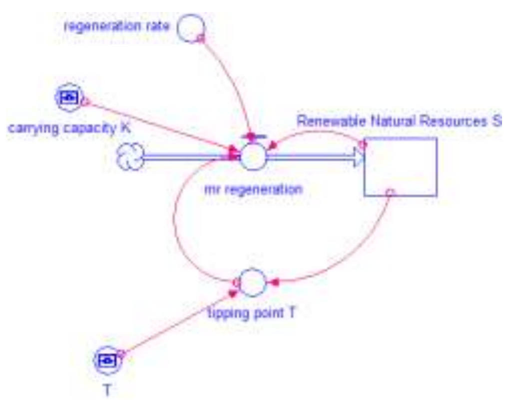
4) Linkage between industrial and local economy is made through non-local spending in the local economy. For localisation of economy policy run, the non-local spending is reduced to 0.01 and the model runs only local economy and renewable natural resource sectors.

Comparing Resource Growth and Economy Growth Dynamics

An important distinction that needs to be highlighted is the difference in the growth structure of natural resources and the economy (ref figure 11 & 12).

The growth of natural resources depends on its own level of stock, but does not compound infinitely. This is because natural resources have an inherent carrying capacity – a maximum value that the stock can attain (Schreiber, 2011)(Ford, 2009). As a result, the growth rate slows down when the stock value approaches its carrying capacity. Moreover, a continuous decline in the resource stock could breach the tipping point, leading to a loss of the regenerative capabilities of the resource.

By contrast, economic growth is exponential in nature. Conventional economic theory does not put any cap on long-run economic growth unless there are external resource based constraints. Unlike the resource growth dynamics which has an endogenous growth limit due to its carrying capacity, the economy does not have any such self-limiting carrying capacity. Although in matured economies the growth rates declines, it never stabilizes at zero or goes negative. Thus the economic growth curve is exponential in nature while the resource stock grows and achieves stagnation.



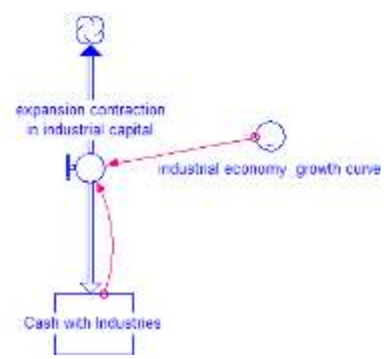


Figure 11 Renewable Natural Resource Growth Curve   Figure 12 Economy Growth Curve

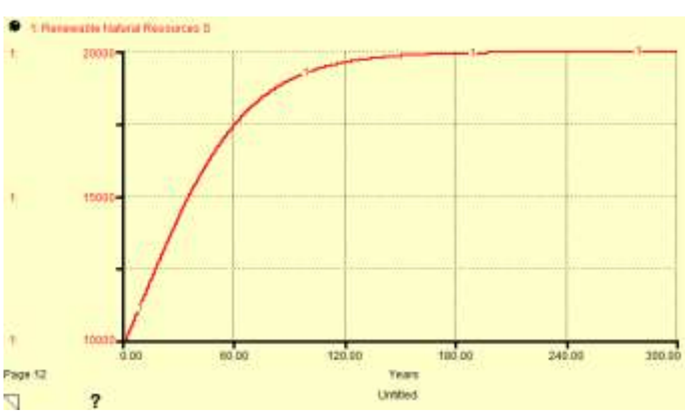


Table 1 Parameters for Base Case

Parameter	Value
Initial renewable natural resources	10,000 kg
Natural resources' regeneration rate	4%
Resource intensity of the economy	1 kg/INR
Local economy's growth rate	2%
Industrial economy's growth rate	1-7%
Initial Wealth with households	INR 10
Initial Cash with Local cottage industry	INR 10
Initial Cash with Industries	INR 10

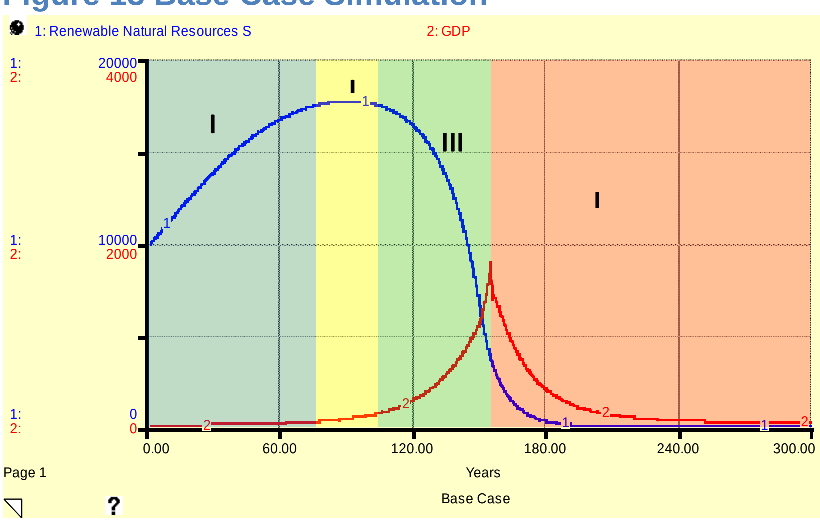
Scenarios and Policy Testing

Base Case – Integrated local and industrial economy

Model Parameters for Base case:
Industrial Economy's Growth Rate = 1% to 7%
Resource Intensity of Economy = 1kg/rupee
Renewable Resource Regeneration Rate = 4%
Local Spending fraction = 0.5
Non Local Spending fraction = 0.5

The base run shows four phases of growth and decline in the resources and economy. Phase I where both Renewable Resources and Economy are growing because of small size of economy and thus lower consumption rates, followed by phase II where due to growth in the economy the resource extraction flows equal regeneration flows leading to stagnation of resource growth while GDP continues to grow, then phase III where a delay between resource and economy is seen when resources begin to decline while GDP growth continues, and finally Phase IV where GDP peaks and declines accompanied by irreversible decline in resources.

Figure 13 Base Case Simulation

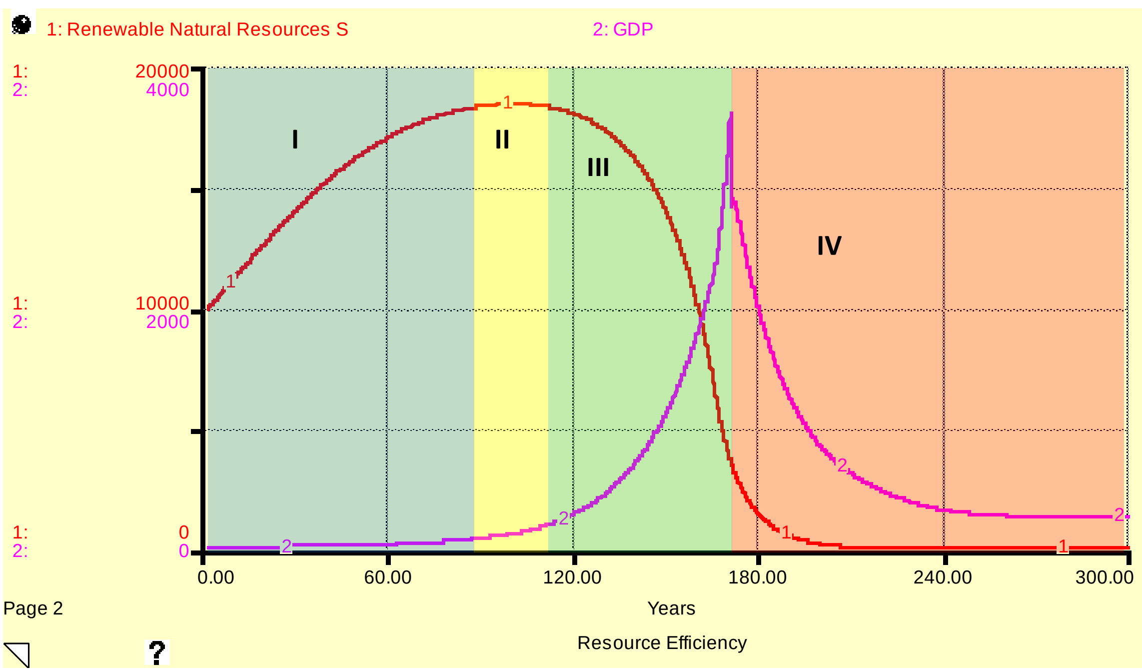


The economic impacts of resource depletion are seemingly invisible during phase I, II and III of the simulation time due to the time lag between exploitation of natural resources and the manifestation of its effects on the economy. As a result, the economy grows while the resource stock continues to fall. A decrease in the stock of resources over time makes it harder to maintain higher extraction rates. Thus the outflow of consumption of resources decline which results into peak in production of goods after which the production flow falls and sustaining the output becomes impossible. However, if the stock of resources has gone below its tipping points then the economy and renewable resources go into an irreversible decline as shown in Phase IV.

Improving resource efficiencies i.e. more economic output per unit of resource

Model Parameters for Resource Efficiency Scenario:
Industrial Economy's Growth Rate = 1%-7%
Resource Intensity of Economy reduced to 0.5 kg/rupee from 1 kg/rupee
Renewable Resource Regeneration Rate = 4%
Local Spending fraction = 0.5
Non Local Spending fraction = 0.5

Figure 14 Improving Resource Efficiencies Simulation

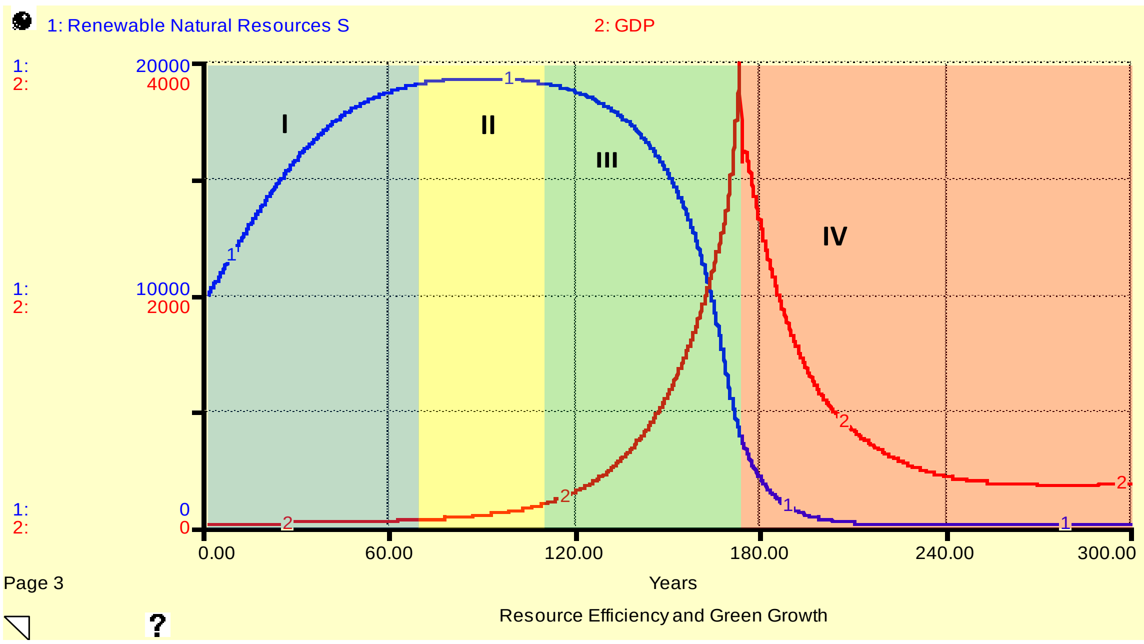


The above scenario models outcomes of an intervention which results into increase in resource efficiency of the economy by 50 per cent (Resource Intensity reduced from 1 kg/rupee to 0.5 kg/rupee). This implies that the economy will consume half the resources compared to the base case. The result shows that the economy would grow more and for a relatively longer duration as compared to the base case. However, the four phases of growth and decline still remain. This shows that while improving resource efficiency of the economy is able to sustain growth for relatively longer time it still is unable to avoid the overshoot and decline in the economy.

Green growth scenario

Model Parameters for Green Growth Scenario:
Industrial Economy's Growth Rate = 1%-7%
Resource Intensity of Economy reduced to 0.5 kg/rupee from 1 kg/rupee
Renewable Resource Regeneration Rate increased to 6% from 4%
Local Spending fraction = 0.5
Non Local Spending fraction = 0.5

Figure 15 Green Growth Simulation



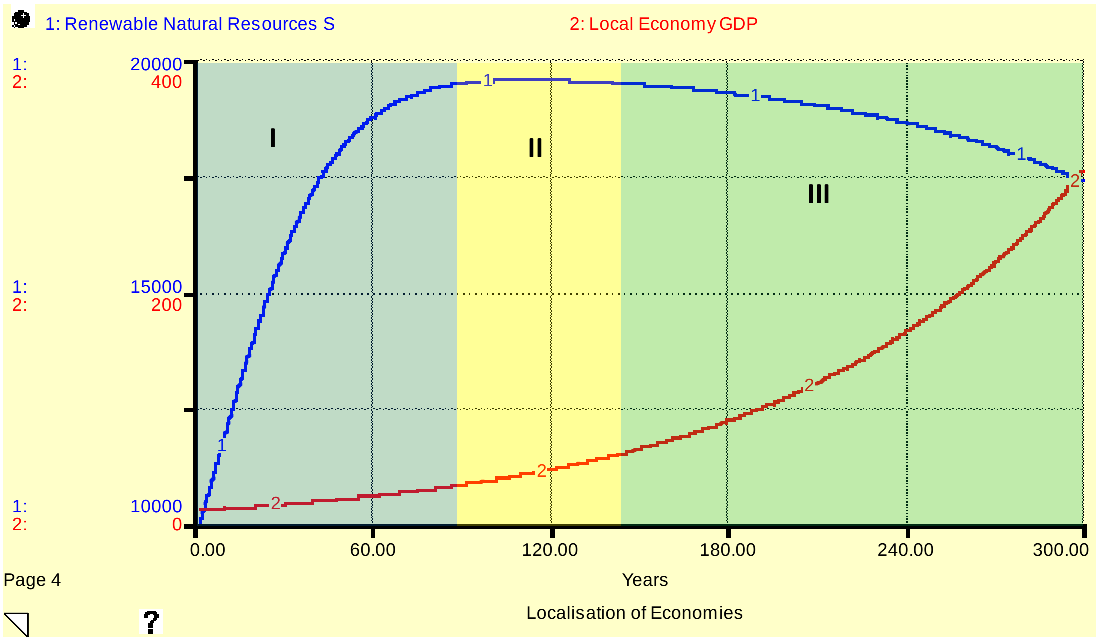
The above scenario models outcomes of an intervention which, in addition to improving the resource efficiency, results into increase in the resource regeneration rate by 50% (Natural Resource Regeneration Rate increased to 6% from 4%). This implies that the economy is actively involved in the resource restoration process, which we have defined as green growth. However, although the rate of regeneration increases, the maximum available stock of resources (carrying capacity) would remain the same. The simulation results indicate that the economy would grow more and for a relatively longer duration. The GDP of the economy grows relatively more as compared to the resource efficiency scenario while the peaking is delayed by few years. However, the ultimate outcome remains the same, i.e. decline in resource stock and overshoot and decline of economy.

Localization of Economies – Local economies relying only on local exchange of goods

Model Parameters for Localization of Economies Scenario:
Industrial Economy's Growth Rate = 1%-7%
Resource Intensity of Economy reduced to 0.5 kg/rupee from 1 kg/rupee
Renewable Resource Regeneration Rate increased to 6% from 4%

Local Spending fraction = 0.99
Non Local Spending fraction = 0.01

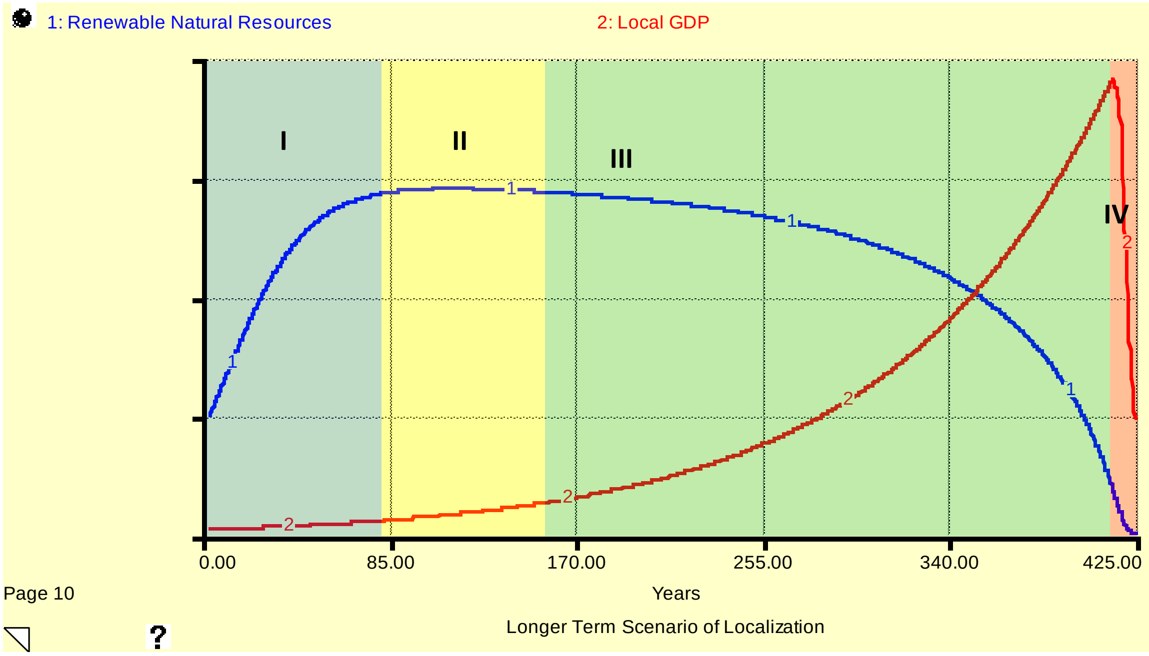
Figure 16 Localization Simulation



The above scenario models outcomes under localized economy conditions which have almost no interaction with industrial economy. This scenario is conceptualized as localized economies which are self-reliant on locally produced goods. The simulation results indicate that the local economy is able to continue to grow throughout the simulation time. The fourth phase i.e. fall in the economy does not happen under localized economy conditions. This implies that the renewable natural resources are not getting depleted to the extent that its feedback is being felt by the economy in the simulation time.

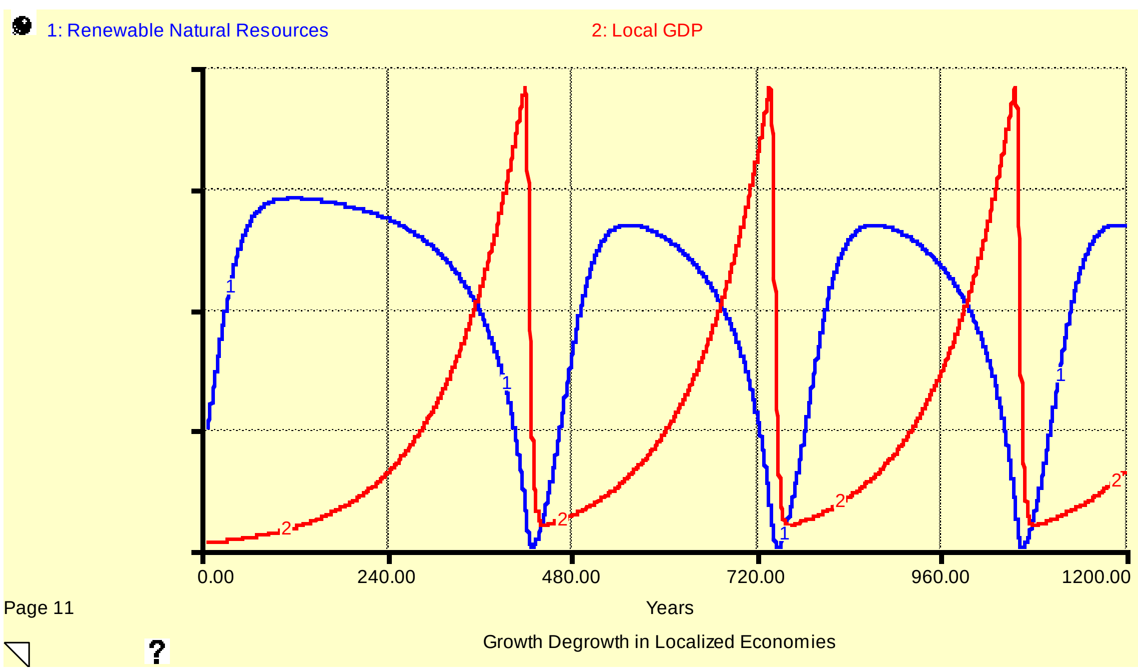
Discussion and Conclusion

Figure 17 Longer Term Scenario for Localization



If the timeframe is extended then the localized economies enter phase IV and eventually fall due to depletion of renewable resources (ref fig 17). This implies that even if local economies become self-sufficient and have a slow growth rate they can't grow perpetually. Over longer time frames the economy would grow to an extent that it would cause resource depletion and undergo correction.

Figure 18 Long Cycles in Localized Economies



On further extending the simulation time the stocks of resources and economy move in oscillations (ref fig 18). It is important to note that the resource stock is able to regenerate itself after having a steep fall and in response the economy is able to again grow after correcting. This implies that the economic consumption of resources does not lead to renewable resource depletion beyond their tipping point. Hence, allowing it to regenerate itself. This could be attributed to presence of a fast feedback structure in the localized economies. This feedback is from stock of renewable resources to the economy. The feedback relationship is modelled from decreasing levels of stock of resources which reduce production capacity and subsequent spending in the local economy. The relationship is drawn from stock of renewable resource as against from flow of renewable resource in industrial economy. The assumption being that a closed economy relying on traditional forms of production would feel the impacts of declining resources much faster than industrial economy. Thus, due to presence of fast feedback from stock of renewable resources, the localized economy is never able to breach the resource tipping points and continues to move in oscillations. Whether these oscillations bring stability and keep people's confidence in the local economy is a question of further research. However, amongst all scenarios modelled in the paper, Localization seems to be a winner.

Insights

Our model is successful in testing the impact policy choices have on the resources and economy. The four stages of growth and decline hold true even under conditions of improved efficiency and green growth. While localization is successful in avoiding the overshoot and decline, under the given simulation time, it still does not escape economic correction and oscillations over longer time frames. This indicates that the causes of limits to economic growth are not truly rooted in inefficient resource extraction or lack of resource restoration. As long as the economy continues to grow its scale of resource consumption would cause resources to deplete under any scenario. And if the economy depletes the resources beyond their tipping point, then an irreversible decline in economy is an inevitable outcome under any scenario.

The following are the insights derived from the modelling exercise which help develop a theoretical understanding on the key dynamics responsible for causing the counterintuitive outcomes of interventions:

1. The stock of resources has a maximum carrying capacity beyond which it cannot grow while there is no endogenous carrying capacity (other than due to external resource constraints) for the economy to stop its growth.
2. As long as the growth in the size of economy is not controlled it would neutralize efficiency and conservation/restoration gains ultimately failing to reach desired goals.
3. Once the economy has grown for too long, a zero growth policy may fail to sustain the resources due to the continuation of large consumption flows coming from large scale economic activities.

Dynamic Sustainability Pathways

To achieve ultimate sustainability, the world at all scales – global, national, regional – needs to move towards achieving economic-ecological dynamic equilibrium. Small economies relying on local exchange of goods and having slower growth rates could enable transition towards such equilibrium. However, the growth of economy would need to be controlled thereby limiting its size of consumption. In real world situations if there are indications which suggest that our economy has over grown and resources are on the verge of their tipping points then controlling further growth would also prove to be futile because of large consumption flows coming from large scale economic activities. It would call for temporarily de-growing of the economy.

At present there are few existing examples in the policy discourse which consider reducing consumption in absolute terms (not efficiency of use) as a measure to achieve the balance between the economy and the resources. In this respect empirical studies, aimed at finding real world solutions, would need to be done based on the theoretical construct that this paper offers.

The research could focus on the following questions to improve the body of knowledge using which solutions could be deliberated upon.

1. What size of economy is desirable to maintain sustainable ecology of resources?
2. What forms of livelihoods would work when the economy undergoes correction?
3. What are the enabling conditions to reduce economic growth and move towards sustainable economies?
4. How could automated fast feedback mechanisms from resources to economy be built to make economy proactively responsive towards the state of resources?

Acknowledgements

This work is an outcome of efforts made by many scientists, ecologists, economists, modellers, thinkers and practitioners on the nature of the relationship between humans and natural resources. Some of them began their work well before anybody anticipated a remote need of it. By putting the existing knowledge into a system dynamics model, this paper attempts to draw synthesis of these knowledge pieces. The outcomes and insights drawn from the modelling exercise provide interesting points for developing an ecological-economic vision for policy making.

The authors wish to thank and acknowledge the following people whose contribution was instrumental for improving the quality of this paper. All errors still remaining are responsibility of the authors.

Prof. Kanchan Chopra, who reviewed the early drafts of this paper and gave valuable feedback and guidance on improving the body of the paper. Prof. Pratap K J Mohapatra, who gave important technical comments and inputs on how to improve the model during the model development process. Our colleagues Saahil Parekh, Aayushi Awasthi and Arpita Bisht with whom we submitted the first version of the paper and presented at the Indian Society of Ecological Economics (INSEE) conference in January 2016. We would like to thank Indian Society for Ecological Economics who gave us the opportunity to present the findings of the paper in their 8th Biennial Conference in January 2016. Dr. Khalid Saeed, for providing clarity on how the model flows relate to the GDP formula used in mainstream economics. Finally we are grateful to The Energy and Resources Institute, New Delhi, for providing us the platform and resources to carry out this work.

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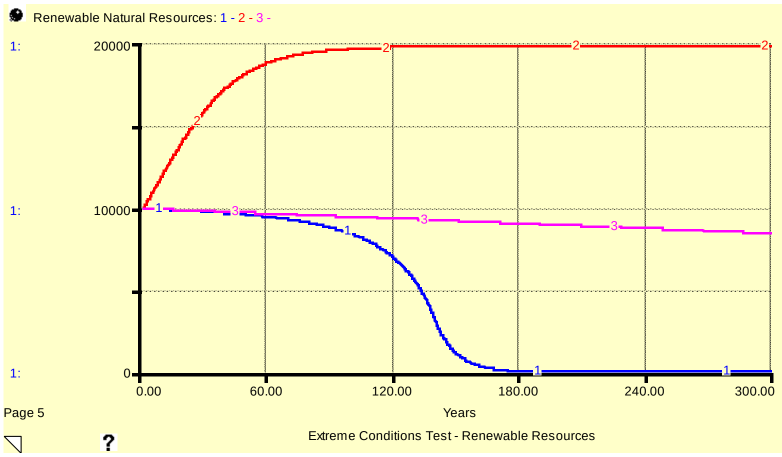
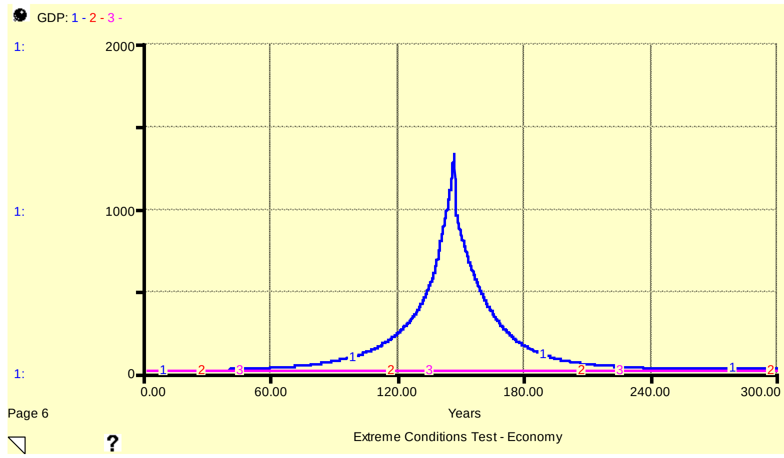
Annexure

A. Extreme Conditions Test



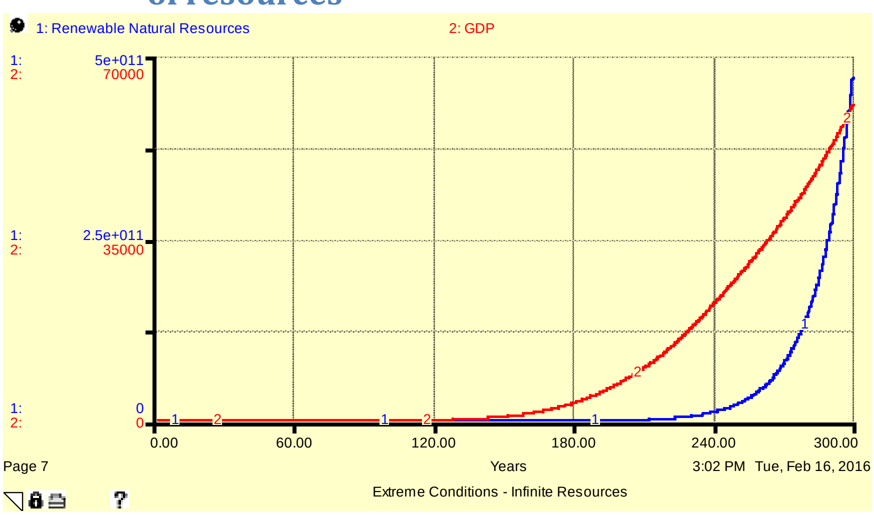


1. Renewable Natural Resource Regeneration Rate = 0

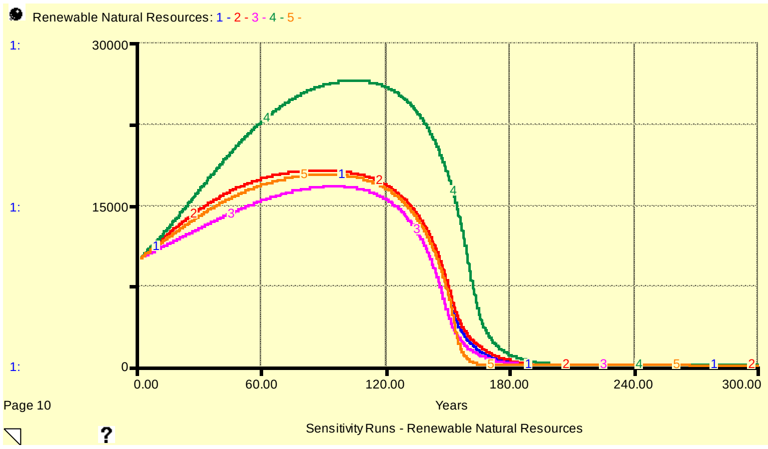
2. Economy growth rate = 0

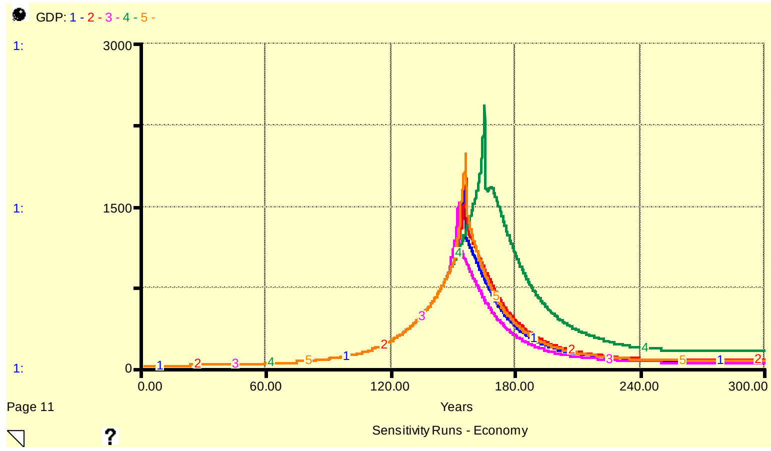
3. RNR and Economy growth rate = 0

B. Growth of economy and resources in absence of carrying capacity of resources



C. Sensitivity Runs





1. Base Run
2. Late Resource Tipping Point
3. Early Resource Tipping Point
4. Carrying capacity doubled
5. Maximum extraction fraction doubled