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Economic development on a finite planet with stochastic soil degradation

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A B S T R A C T

World economic development is associated with growing food consumption. Agricultural land, however, suffers from over-exploitation and is subject to environmental shocks which are projected to become more severe due to climate change. We present a stochastic model of a dynamic economy where soil is an essential input and natural disasters are sizeable, multiple, and random. Expansion of economic activities raises effective soil units but contributes to an aggregate loss of soil-protective ecosystem services, which exacerbates soil degradation at the time of a shock. We provide closed-form analytical solutions and show that optimal development is characterized by a constant growth rate of stocks and consumption until an environmental shock arrives causing all variables to jump downwards. Optimal soil management consists of spending a constant fraction of output on preservation measures, which is an increasing function of the shocks hazard rate, degradation intensity of agricultural practices, and the damage intensity of environmental impact. We derive the optimal propensity to save and discuss the impact of human pressure and risk exposure on soil and output. We also discuss quantitative impacts of climate change on optimal soil management.

1. Introduction

1.1. Soils at risk

Rising food demand and growing risks of large-scale land degradation suggest bringing back to macroeconomics what is by now the “nearly forgotten resource” – soil.[1] It is estimated that by 2050 agricultural production will have to rise by 70% to meet the needs of growing world population (FAO, 2009).[2] However, already nowadays about one third of all soils are degraded and the global amount of productive land per person could in 2050 be only one-fourth of the level in 1960,

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[1] The expression “forgotten resource” is prominently used in FAO (2014). In France of the 18th century the physiocrats saw land as the primary generator of wealth. Classical economists such as Adam Smith and David Ricardo used it as one of three inputs into production. Ricardo (1817) starts his famous “Principles” by talking about “the produce of the earth.”

[2] Lanz et al. (2017) empirically estimate an endogenous growth model with finite land reserves to study the long-run evolution of global demand for food and find that agricultural production will double by the end of the century.

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if current management practices and policies remain unchanged.[3] A moderate interpretation of U.S. President Franklin D. Roosevelt's quote that "A nation that destroys its soils destroys itself" would read that important aspects of well-being like food security, human health, clean air, and clean water are at risk when quantity and quality of world's soils are not taken care of Wall and Six (2015). The challenge is amplified by changing weather patterns and climate variability, which force farmers to adopt ecosystem-unfriendly practices. This provides ample motivation to study the consequences of endogenous stochastic land degradation for long-run development.[4]

Soil cultivation raises availability and productivity of arable land but involves major risks and uncertainties. In fact, risk is an inherent element of all agricultural activities. The development of agriculture itself was a response to the risks of relying on hunting and gathering for food (Hardaker et al., 2004). The impact of risk has not disappeared, of course, but it has changed its character and has shifted to different areas. It is still inevitable, because food markets are closely interlinked with the rest of the economy and, in particular, because ecological systems and weather conditions are increasingly subject to perturbations. Many developing countries experience large variations in rainfall and are subject to frequent extremes of flooding or drought, both of which contribute to soil erosion and land degradation (UNEP, 2015). Drought and erosion are exacerbated by poor land management that responds inappropriately to climatic variations (UNCCD, 2009), which are predicted to increase in frequency and severity due to climate change, increasing land degradation even further (UNCCD, 2013).

Important negative effects on soil quality arise from the agricultural sector itself, creating potentially harmful changes in the ecological systems supporting the farms (Lichtenberg, 2002). For example, land use changes, irrigation, or deforestation may cause soil erosion and nutrient depletion. The use of pesticides, animal wastes, and soil siltation may contaminate surface and ground waters. Salinization of rivers may damage crop production in downstream areas, while irrigation and land clearing may lead to land loss to selenium and salt drawn up from subsoils. Degradation is often due to increased disruption of macroaggregates, reductions in microbial biomass, and loss of labile organic matter which are induced as negative externalities from aggregate economic activities. Under appropriate market conditions, farmers are able to respond to risks in an optimal manner. However, institutional deficiencies, such as incomplete land tenure systems as well as negative externalities from individual farming on aggregate soil protection, cause suboptimal development. Also, the lack of information about the impact of soil shocks and high individual rates of impatience may constitute management problems for soil.

Soil degradation can be addressed by different types of corrective measures. Labrière et al. (2015) empirically estimate the impact of contour planting, no-till farming and use of vegetative buffer strips on the reduction of soil erosion and find enormous potentials. They conclude that the government or natural resource managers can help decrease soil losses on a large scale. It has been stressed in the literature that such measures can be implemented by individual farmers, by farmer cooperations, or via public policies.[5]

It is often stated that human pressures on soils are reaching critical limits, reducing and sometimes eliminating essential soil functions (Islam and Weil, 2000). Human pressures may entail unsustainable land use and vulnerability to land degradation, including overcultivation, overgrazing, poor irrigation practices, deforestation, and polluting industrial activities (UNCCD, 2009).[6] Food production and security are global concerns but soil losses are especially acute in arid, semi-arid, mountainous, or tropical regions where the lack of protection may cause substantial deterioration in soil quality and reduction in yields. These types of environmental problems in production and food provision and their link to general economic development warrant a thorough investigation from a theoretical perspective.

1.2. Model and findings

We develop a dynamic model of an economy where investments increase the capital stock and the effective soil stock, defined as an index of soil quantity and quality. Investments in agricultural expansion have positive output effects but may also entail negative impacts on soil quality. For instance, clearing and fertilizing of soils are aimed at raising land productivity and profits but may, at the same time, harm the functioning of the ecosystem making it more vulnerable to degradation and natural disasters such as floods, droughts, storms, landslides, etc. The latter may typically have large economic consequences and at the same time are not easily predictable. We therefore model such calamities as random shocks. Our model refers to a planner internalizing such external effects in the economy. This is a generic approach to policy, so that we do not have to specify whether the political actors are public or private and, similarly, domestic or foreign.

The paper addresses several specific research questions. We first ask about the long-run development prospects of an economy which is subject to endogenous stochastic soil degradation. A second issue concerns optimal management practices and optimal public policy in the presence of random shocks. We specifically inquire about the optimal balance between economic expansion and protection of existing soils. Our model delivers closed-from analytical solutions for the optimal

[3] The scenario assumes world's population will reach 9.1 billion in 2050 (FAO, 2014).

[4] Another reason that soil has recently come roaring back is the land scarcity in agglomerations and associated income losses (Economist, 2015).

[5] Studying alternatives to governmental policies, Lopez (2002) deals with the endogenous evolution of rural environmental institutions which is particularly relevant for poor tropical areas where the agricultural and natural resource base is fragile.

[6] For example, there is a widespread concern that the clearing of Asia's upland mountain forests exacerbated the damages from floods in Bangladesh, Cambodia, China, India, Thailand, Vietnam and elsewhere in the Asian lowlands. Transboundary floods that affected India and Pakistan in 2014 resulted in losses of at least US$ 18 billion; the largest damage was the river basin flood in India causing 1281 fatalities and a loss of US$ 16 billion.