Uninsurance through trade*

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Abstract

One of the main gains from trade is increased consumption variety. Likewise, variety through trade implies a form of insurance to idiosyncratic shocks from, for instance, floods and fires. The mechanism behind the insurance is that an increasing relative price of goods from the negatively affected country enables faster recovery. We show that when there is open access to a renewable resource these results are reversed. A country hit by negative shocks fares better if trading with fewer countries, and if it is trading with many, it gains if all its trading partners are hit too. This way natural disasters will imply larger economic volatility when trading and, for a single country, local disasters will be worse than global. We also show that a natural disaster in one country can cascade into a man-made disaster in competitor countries.

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1 Introduction

In recent years the over-harvesting and collapse of several important food-sources has caught the attention of policy-makers and the media. This has been spurred by a large number of alarming scientific reports showing that several renewable resources are in a poor state, most notably fish. This is a particularly large problem in developing countries, being the most reliant on fish both for their consumption and in their production and exports. According to the Food and Agriculture Organization of the United Nations (FAO, 2012) fish alone provides for one sixth of all animal protein globally, and more than one half in some developing countries (e.g. Bangladesh, Cambodia, Ghana, the Gambia, Indonesia, Sierra Leone and Sri Lanka and some island states). Following the Rio+20 meeting, many have recognized the importance of governance (i.e. proper management) in dealing with food security in the developing world (ibid). Implementing proper management practicies is typically more difficult in developing countries since they are often unable to control their land and waters from both domestic and foreign illegal harvesting (ibid). The problem is so vast that it has led to UN general assembly resolutions on this issue (UNGA Resolution 65/38).

During a number of decades international trade with renewable resources has increased significantly. For instance, in the period 1976–2008, world trade in fish and fishery products rose from US\$8 billion to US\$102 billion, with annual growth rates of 4 percent in real terms (FAO 2012). In volume terms, the share of fish exported has been increasing steadily and corresponded, in 2009, to around 40% of all fish. This represents 1% of all merchandise exports and involves 197 exporting countries (ibid). The role of fishery trade is important, in particular, for developing nations and in some countries fish represent as much as half of all exports (ibid). Fish represents by far the largest net exporting of agricultural commodities in developing countries and today more than half of all exported fish comes from developing countries (ibid).

Indeed, this growth in fishing has implied both over-fishing, with many fish populations being harvested at only half of their historical maximum, and outright collapses of for example Newfoundland cod and several whale species (Hillborn, 2003). A recent study even suggests that one out of four fisheries has collapsed in the last 50 years (Mullon et al, 2005). It is estimated that around a third of all marine fish stocks are overexploited (FAO, 2012). Facing diminishing returns of traditional fish stocks, the catch increase has come mainly from fishing of new species and at more inaccessible locations – at the high seas where property rights are even less clear (Cullis-Suzuki & Pauly, 2010).

The dynamics of overharvesting are not confined only to fisheries. As a consequence of the falling yield rates of fisheries the hunt for bushmeat has increased significantly in West and Central Africa (Brashares et al 2004, Damania et al 2005, Waite 2007). For centuries there has also been trade with wild animals shot by poachers. This has led to near collapse of species such as rhinos. Other examples of collapses directly attributed to trade are those of buffaloes in North America (Taylor, 2007) and hardwood in the Philippines (Bee, 1987; Kummer, 1992).

What these industries and cases all have in common is that there is open access to harvesting the resources – either legally (like in many fishing areas) or in practice (like with poaching). This leads to over-harvesting and the familiar "tragedy of the commons" (Hardin, 1968; Loayza, 1992). When there is open access to a renewable resource the harvesting decision of individuals today will not incorporate the effect on the harvest tomorrow. The aggregate outcome is then over-harvesting of the resource away from what is socially optimal.

In a recent paper, Quaas & Requate (2013) show that consumer preferences for variety when eating fish can exacerbate overfishing when there is open access. These results naturally hold for other renewable resources too. Using a similar setup we extend their analysis to evaluate welfare gains from international trade and, in particular, the effect of natural disasters and how trade may lead to uninsurance – i.e. an enhancement of the negative economic effects of the disaster. Being so reliant on trade and consumption of renewable resources, if a natural disaster kills or destroys part of the resource stock this is indeed a serious issue in the developing world. We also analyze the effect of positive TFP shocks among one's trade partners on harvest, collapse and welfare.

Our analysis of the welfare effect of increased trade openness combined with open access to renewable resources decomposes the net effect into two opposing effects. Firstly, the variety effect improves welfare since trade enables consumption of a more varied basket of goods. It has been estimated that the welfare gains from variety through trade from 1972-2001 in the US counts for an equivalent of 2.6% of GDP (Broda & Weinstein, 2006). Indeed, research shows complementarity to exist between many fish species (e.g. Barten & Bettendorf, 1989; Bose & McIlgrom, 1996). This effect may wear off but remains positive also when the number of trading partners becomes large. Secondly, a negative stock effect comes about as the increased demand for the resource from other countries makes harvesters willing to exert more effort. Since it is more cumbersome to harvest a sparse resource the productivity of harvesters falls. We show that the relative weight of the stock effect increases as more trading partners are added when there is open access. This leads to welfare being hump-shaped in the number of trade partners – opening up for trade with more countries increases welfare up to a certain point after which additional increases in the number of trading partners decreases welfare. If the resource is sensitive enough, this may even lead to the resource collapsing.

Next we consider the effects of trade when natural disasters occur. The disaster may strike in the form of a storm, a flood, a fire or disease that kills part of the resource stock. A standard result in macroeconomics is that idiosyncratic shocks of this kind (to an individual or a country) are preferable over symmetric ones. The reason is that idiosyncratic shocks can be insured against, which is harder if all countries are hit by bad times all at once. This is, under normal circumstances, also a motivation for trade. If one country has, say, half its factories devastated by a flood then, assuming that countries produce differentiated goods, the price of their good goes up which enables them to rebuild their factories faster than if they were not trading. International trade then works as an insurance. This is reversed when there is open access to a renewable resource. The reason is quite simply that a negative shock to a country's resource stock, for example by having half their fish population die from a disease, leads to an increase in the relative price of their resource as supply falls. The price increase will then lead to even more extensive overharvesting in the single country which implies a longer time for recovery and that the risk of collapse increases. Had the shock been common to all countries then this price effect would not have occurred and hence collapse would have been less likely and recovery would have been faster. To be more precise, holding all else equal, the size of the negative shock needed to create collapse is smaller if the shock is idiosyncratic. Likewise, the more countries that are trading the more likely it is that a shock will lead to collapse. Had there been no trade there would not have been any increase of the relative price of the country's resource following a negative shock. This means that the economic impacts of natural disasters will be aggravated by trade. Now, the price effect also has its benefits. It increases the income for any given harvest in the affected country. The question then is whether the short run price effect overshadows the long run effect of slower recovery or collapse. We show that if a country is beyond the optimal degree of trade openness (in the hypothetical world without shocks), then negative shocks to its trading partners are good.

In an extension to the model we consider a case where groups of countries each have the same resource. That is, within a group all countries compete in selling the same resource. We show that a natural disaster hiting one country can cascade into a man-made collapsing of the stock in countries having the same resource (but who were not themselves hit by the natural disaster). This is since if one country within a group is hit by a disaster lowering its stock, then this will lower total supply of that resource implying a price increase. Following the price increase the competitor countries will increase their supply and they may, hence, collapse the stock. This effect becomes more pronounced the more trading partners (selling a variety of goods) a country has. This way trade and the world market works as a mechanism of contagion of natural disasters.

Finally, we analyze positive TFP shocks to one's trade partners. This has a similar effect as a natural disaster in the own country. The increased TFP of the trade partners increases the price of ones own resource which leads to more overharvesting and potential collapse. This holds true not only if the increased TFP is permanent. Also a temporary increase in TFP may lead the country to a state of collapse.

There is a broad empirical and theoretical literature showing that resource rich countries often do worse than resource poor countries (see van der Ploeg, 2011 for a survey). One of the mechanisms proposed is that increased prices of a country's commodities may lead to increased corruption and conflict (see e.g. Dal Bo & Dal Bo, 2011, for a general equilibrium model). In effect we show in this paper that both TFP shocks and natural disasters provide an alternative channel for the resource curse highlighting the importance of economic institutions such as property rights. Our model stresses not the conflict or corruption generated by price increases but rather the overharvesting and worsening of the tragedy of the commons. It also stresses that countries trading extensively will be more economically vulnerable to natural disasters and to collapsing of fisheries, wildlife and ecosystems.

The research concerning trade with open access renewable resources was pioneered by Chichilnisky (1993) and in a series of papers by Brander & Taylor (1997a, 1997b, 1998). Brander & Taylor (1998) set up a two country, two sector, trade model where one of the sectors relies on a renewable resource to which there is open access. In this setting trade induces specialization so that the resource abundant country harvests more. The conclusion is that, comparing the outcome with trade to the autarky outcome, welfare increases in the labor abundant country and decreases in the resource abundant country. A few papers have since then elaborated upon these results. Regarding specific trade structures Lopez (2000) shows that the type of openness affects whether there are gains or losses from trade. In regard to forms of property rights Nielsen (2009) shows that there may be gains or losses from trade depending on the management scheme; Engel et al (2006) show that third party involvement in mediations for control over the resource may incur losses; Emani & Johnston (2000) show that unequal property rights between trading countries may in itself be a problem. In regard to the biological effects Smulders et al (2004) analyze the effect of trade on habitat destruction and welfare. Finally, regarding industry and country assumptions, Hannesson (2000) shows that diminishing returns in the non-resource sector can lead to gains from trade in situations where there would be losses without the diminishing returns. Finally, Copeland & Taylor (2009) endogenize the institutional settings and hence show how the very presence of an open access regime is affected by trade and world prices. The main contribution of our paper in comparison to the previous literature is to analyze the effect of natural disasters on harvest, collapse and welfare.

The rest of the paper is structured as follows. In the next section we set up the model and derive results for the effects of increased trade openness on steady-state variables. Following that, in section 3, we consider natural disasters that manifest themselves as shocks to the resource stocks in a single country or a group of countries. We then, in section 4 analyze a case of more than one country having a certain resource. In section 5 we generalize the analysis by no longer assuming that all countries are exporting goods harvested from renewable resources. Finally, section 6 concludes. The main body of the paper contains only analytical results necessary for describing and understanding the central results in the paper. Most proofs, derivations and supplementary analytical results are to be found in the appendix.

2 Model setup and steady-state analysis

We start by analyzing a case where there is a continuum of countries.[1] Each country has a unique type of a renewable resource provided by an ecosystem.[2] This resource can be thought of as a fish species or any wildlife, forest or plant which can be sold on a market. The model possibly best represents the case where, for example, one country has a fish stock, another country has a forest and a third country has a game population. We further assume that there is a continuum of mass

[1] We make this assumption to enable differentiation with respect to the number of trading partners, J. If J is an integer, the results are the same as what they would be if there were J discrete countries. This means that $J = 1$ represents the case of autarky.

[2] For tractability, we assume that the resource sector is also the only sector in the economy. We therefore restrict the interpretation of our analysis to correspond to gains from trade with these types of goods. A richer model could of course include also other sectors but, intuitively, we don't think this will have an effect on the results since the general effect will still be present. I.e. when opening up for trade the price of the resource good goes up which will either attract more workers into this sector or increase the efforts of the present workers. This in turn will lower the stock and possibly decrease utility.

one of agents in each country, who all work with harvesting from the renewable resource, to which there is open access. In the exposition of the model and results we will use specific functional forms. The results are, however, generalizable. The functional forms we choose are simply more effective in highlighting the results and driving mechanisms.

Utility of the representative agent in country i is given by

$$U_i = \left(\int_0^J (c_i(j))^q \, dj \right)^{\frac{1}{q}} - AN_i^\theta \tag{1}$$

where $c_i(j)$ is the consumption of the good from country j by an agent in country i and N_i is the harvesting effort of an agent in country i. The parameter θ determines the shape of the effort cost function while A is the weight of work disutility. The disutility of harvesting effort can also be interpreted as an alternative cost in terms of reduced production of non-traded goods. We will assume that $\theta > 1$ so that the marginal cost is increasing in effort. J denotes the mass of countries that country i trades with. Unless otherwise stated, trade openness and trade liberalization will be used synonymously for an increase in J. When considering resources such as fish, wildlife and plants it seems reasonable to assume that the different varieties of goods are fairly good, but not perfect, substitutes. That is, we assume that $q \in (0, 1)$.

Generally, a harvest function $H(N, x)$, where x is the resource stock, should have the property that it is increasing in both its arguments. Here we will use the standard harvest function of Schaefer (1957).

$$H(N, x) = Nx \tag{2}$$

Thus, for a given stock x, harvest is linear in effort N. This means that there will be no (static) externalities between the harvesting efforts of different agents.[3]

An agent in country i faces the budget constraint

$$\int_0^J p(j)c_i(j)dj = p(i)N_i x_i, \tag{3}$$

where $p(j)$ is the world market price of the good from country j and x_i is the stock of the resource in country i. Total world consumption of the

[3]We have also looked at the harvesting function $H(N, x) = Nx^\beta$ where $\beta < 1$. With that specification, overharvesting becomes a larger problem in the sense that collapse is possible for a larger range of parameter values (including logistic growth) and that the steady-state stock, where utility starts to decrease with trade openess, is larger.

good from country j must be equal to the harvest in that country

$$\int_0^J c_i(j)di = N_j x_j. \tag{4}$$

Given the assumption of open access, and an infinite number of agents, the harvesting decisions will be static and not take the effect on the stock into account. This means that the harvesting rule for the agents can be written as a function of only the current resource stocks $\{x_i\}$ and the parameters of the problem. The representative agent thus wants to maximize (1) subject to (3). The solution must also satisfy (4). Solving this problem yields the following set of equations.

$$U_i = (\theta - 1)AN_i^\theta \tag{5}$$

$$N_i = (\theta A)^{\frac{1}{1-\theta}} \left[\frac{\int_0^J x_{i'}^{\frac{\theta q}{\theta - q}} di'}{x_i^{\frac{\theta q}{\theta - q}}} \right]^{\frac{1}{\theta - 1} \frac{1-q}{q}} x_i^{\frac{1}{\theta - 1}} \tag{6}$$

Equation (5) immediately implies the following lemma.

Lemma 1 *Flow utility U_i is strictly increasing in individually optimal harvesting effort N_i.*

Although a high effort N is a form of cost, the lemma implies that it can be used as a proxy for flow utility. The intuition for this is roughly that a higher effort is indicative of a higher marginal utility from consumption. Below we will use this result to determine signs of changes in flow utility. It is important to note that this does not mean that agents do best in exerting a high effort. Rather, N_i is a choice variable for the individual agent, and hence what the lemma says is that when we observe agents exerting a high effort then that is a sign of high utility.

The previous equations describe what the agents do given the resource stocks $\{x_i\}$, i.e. a partial equilibrium reflecting the economic forces of the model but missing the biological dynamics. To get the steady-state of the bio-economic general equilibrium we need to specify what determines the stock size. The resource stock in country i evolves according to

$$\dot{x}_i = f_i(x_i) - N_i x_i \tag{7}$$

where f_i is a biological function denoting the growth of the resource in the absence of human interference. We will assume the same biological growth function in all countries. For expositional purposes we will use the explicit function

$$f(x) = kx^\alpha(1 - x). \tag{8}$$

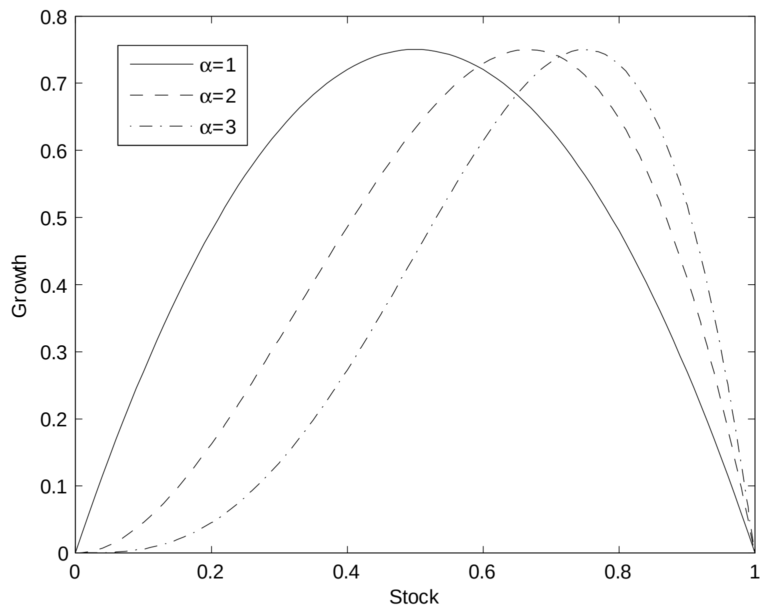

Figure 1: The biological growth function for different values of α.

This is a relatively simple and tractable generalization of the commonly used logistic growth function (e.g. Brander & Taylor 1997a, 1997b, 1998 use the logistic growth function). If $\alpha = 1$, this function represents logistic growth.[4] If $\alpha > 1$, the resource stock is more sensitive to extensive harvesting, so called depensation (see Clark 1990).[5] We depict the function for some different values of α in Figure 1. This function is such that, absent any harvesting, there are two steady-states. One unstable at $x = 0$ and one stable at $x = 1$. That is, over time the stock would go to its maximum size $x = 1$ if there was no harvest. The parameter k represents the intrinsic growth rate. The growth function has a single peak at $\frac{\alpha}{\alpha+1}$. Furthermore, for small x, the function is convex but at some point it becomes concave and remains concave (for $\alpha = 1$, it is concave for all x).

Initially we restrict our attention to symmetric countries in symmet-

[4] Often, the specification is $f(x) = kx(1-\frac{x}{r})$. However, since the parameter r only determines the size of the stock, it can be normalized to one and other parameters can be adjusted accordingly. For reference see Clark (1990).

[5] Note that we do not have critical depensation here. Critical depensation means that there is a threshold such that if the stock decreases below it, the stock will go to zero regardless of harvesting. With our functional form, the stock will always recover without harvesting while critical depensation would enable irreversible collapse of the stock.

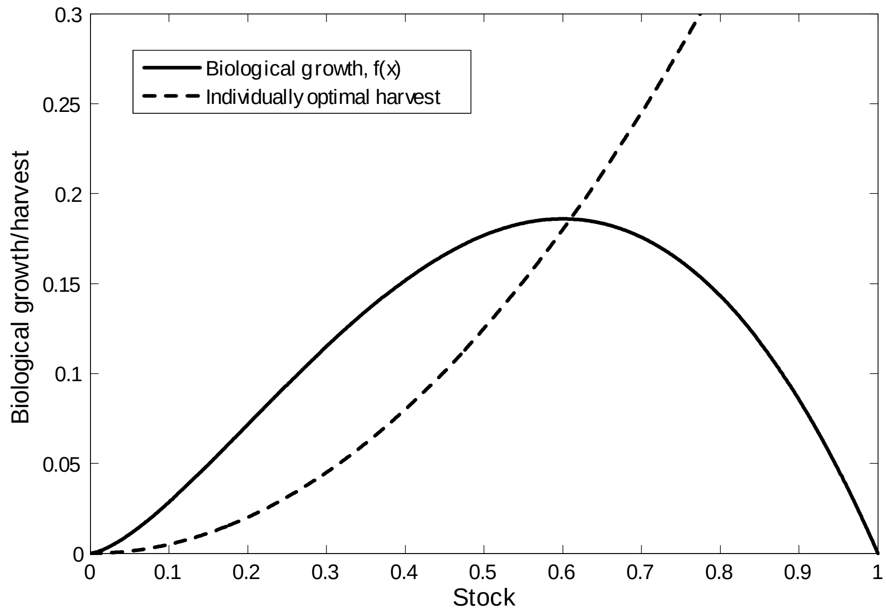

Figure 2: Phase diagram of contributions and withdrawals from the resource stock.

ric steady-states. This allows consideration of the mechanisms determining the welfare effects of increased trade openness. Later, shocks resulting in heterogeneous stocks will be considered. Thus, suppose now that $x_i = x$ and $N_i = N$ for all i and that $c_i(j) = c$ for all i, j. Imposing these symmetries in (5) and (6) and using (2) gives flow harvest and flow utility as functions of the current stock.

$$H = (\theta A)^{\frac{1}{1-\theta}} J^{\frac{1}{\theta-1}\frac{1-q}{q}} x^{\frac{\theta}{\theta-1}} \tag{9}$$

$$U = (\theta - 1)AN^{\theta} = (\theta - 1)\theta^{\frac{\theta}{1-\theta}} A^{\frac{1}{1-\theta}} J^{\frac{\theta}{\theta-1}\frac{1-q}{q}} x^{\frac{\theta}{\theta-1}} \tag{10}$$

The bio-economic dynamics with symmetric countries can be illustrated in a phase diagram for a representative country (see Figure 2). The dashed line represents harvest as a function of the current stock as stated by equation (9). The solid line represents the biological growth function. In the specific case in the figure there exists one stable steady-state where the lines cross. If the stock is above this level, harvest will be higher than the biological growth leading to a falling stock. If, instead, the stock is below the steady-state level, harvest is lower than the biological growth and the stock increases. There exists another unstable steady-state where the stock is zero.

It is straightforward to show existence of a stable steady-state, provided that J is sufficiently low. Graphically, in Figure 2 we can see that as J approaches zero, H approaches the x-axis which implies an intersection with $f(x)$. From this figure it is also immediate that an increase in J will lead to a decrease of the stock (since this tilts the harvesting curve upwards). Similarly, an increase in J will first increase harvest but for sufficiently large J harvest will start decreasing. Finally, under certain conditions we will analyze later, a sufficient increase in J will imply the harvest function in Figure 2 is steeper than the biological growth function when $x = 0$ and hence the harvesting function is above the biological growth for small x. Such a case would imply $x = 0$ is a stable steady-state – a situation we will call (bio-economic) collapse.

One way to analyze the welfare effects of increasing J is to decompose the welfare change into a variety and a stock effect. Where the variety effect captures the welfare gains from increased consumption variety while the stock effect captures the negative consequences of a decrease in the steady-state stock. Starting from equation (10) and taking the full derivative of the flow utility with respect to J yields

$$\frac{dU_{ss}}{dJ} = \frac{\partial U_{ss}}{\partial J} + \frac{\partial U_{ss}}{\partial x_{ss}} \frac{dx_{ss}}{dJ} \tag{11}$$

where $\frac{dx_{ss}}{dJ}$ is the change in steady-state stock that is induced by a change in J. The first term represents the variety effect and the second term represents the stock effect. From (10) it can be seen that $\frac{\partial U_{ss}}{\partial J} > 0$ and $\frac{\partial U_{ss}}{\partial x} > 0$. Since the steady-state stock always decreases with J, $\frac{dx_{ss}}{dJ} < 0$.[6] The variety effect is thus always positive while the stock effect is always negative.[7] Through explicit computation of the involved derivatives it can be shown that the variety effect will dominate when $\frac{f(x)}{x}$ is decreasing in x while the stock effect will dominate when $\frac{f(x)}{x}$ is increasing in x. This can also be understood in terms of Lemma 1 since equation (7) implies that steady-state harvesting effort N must be equal to $\frac{f(x)}{x}$. Standard functional forms for $f(x)$ typically have the property implying a unique cutoff stock above which welfare is increasing in trade and below which welfare is decreasing.[8] For our specific functional form

[6] Graphically this can be seen in Figure 2 – an increase in J tilts the harvesting function upwards which implies a lower x. Analytically this is shown in the appendix.

[7] Note that the steady-state stock may be lower with more trading partners also in the optimal outcome. So, a negative stock effect does not necessarily only capture overharvesting.

[8] The difference between $\frac{f(x)}{x}$ being decreasing and increasing in x is the difference between compensation and depensation. Growth functions are typically assumed to exhibit compensation for large x. If the growth function also exhibits depensation this happens for small x. A growth function is often referred to as being of the depensation type as long as it exhibits depensation for some range of x-values. See Clark (1990) for further discussion of these properties.

this cutoff is $x_{ss} = \frac{\alpha-1}{\alpha}$. I.e., for $x_{ss} > \frac{\alpha-1}{\alpha}$ welfare is increasing in trade and for $x < \frac{\alpha-1}{\alpha}$ it is decreasing. The main symmetric results, using the decomposition into a stock and a variety effect, are summarized in the following proposition.

Proposition 1 *The steady-state stock x_{ss} always decreases with J, and harvest increases with J until $x_{ss} = \frac{\alpha}{\alpha+1}$.*

1. *If $\alpha = 1$ (the logistic case) steady-state utility always increases with J.*
2. *If $\alpha > 1$ (the depensation case) steady-state utility increases with J until $x_{ss} = \frac{\alpha-1}{\alpha} < \frac{\alpha}{\alpha+1}$, after which further increases in J reduce steady-state welfare.*
3. *If, furthermore, $\alpha > \frac{\theta}{\theta-1}$ (the high depensation case) then increasing J beyond the value that gives $x_{ss} = \frac{\alpha(\theta-1)-\theta}{\alpha(\theta-1)-1} < \frac{\alpha-1}{\alpha}$ in steady-state will drive the stock to collapse at $x = 0$.*

Proof. *See appendix.* ■

This proposition highlights a few noteworthy results. Firstly, the logistic case is the only one where trade unambiguously improves welfare. For any degree of depensation there is a maximum number of trade partners after which welfare is falling. Secondly, an important implication of this proposition is that when $\alpha > \frac{\theta}{\theta-1}$, there is a risk of collapse. This is not simply a biological collapse, since absent of harvesting the resource will recover, but a bio-economic collapse which is driven by the interaction of economic incentives and biological properties – agents have incentives to harvest also when the stock is small which refrains it from recovering. Later, when we consider shocks leading to stock asymmetries, we will see that the range of parameter values where there can be collapse is in fact larger than this.

The high depensation case is illustrated in Figure 3. Increased trade openness corresponds to an upward shift in the harvest function. Although it may be difficult to see in the figure, as long as $J > 0$, the harvesting function starts above the growth function implying that $x = 0$ is stable – i.e., there is potential for collapse. For small J, there are two steady-states. One larger that is stable and one smaller that is unstable. If starting from some arbitrary stock, the unstable steady-state gives the threshold below which the stock will go to zero. This may be the effect of a negative shock to the stock, which we analyze in the next section.

The steady-state utility is increasing in J in the stable steady-state as long as it is to the right of the dashed vertical line. When J reaches the

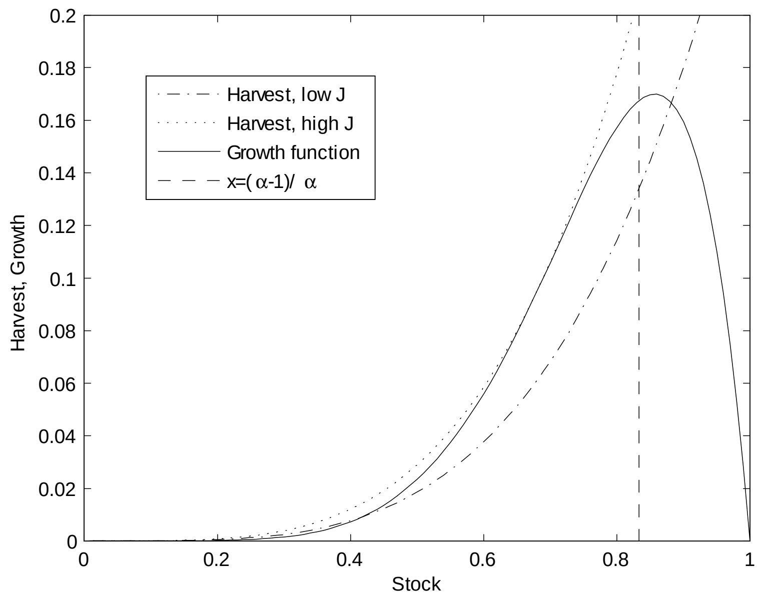

Figure 3: Phase diagram for the case $\alpha > \frac{\theta}{\theta - 1}$.

value corresponding to the dotted harvesting function in the Figure 3, the steady-states become one saddle point. If trade is increased further, there is no longer any steady-state with positive stock and the stock will go to zero regardless of where it starts from. It can be seen that this happens strictly to the left of the dashed vertical line which means that the steady-state utility will start to decrease before the stock goes to zero.

Figure 4 summarizes the main results with regrad to U_{ss} (for a case without collapse). Note that the x-axis is in reverse – going from high to low levels of x_{ss} – to represent increases in J. Leftmost in the graph is the steady state stock in autarky ($J = 1$). As we move rightwards, x_{ss} falls (following an increase in J) which initially leads to a higher utility. At the point where $x_{ss} = (\alpha - 1)/\alpha$ the maximum steady state utility is attained. After that further increases in J lower utility. This means that when $x_{ss}(J) < (\alpha - 1)/\alpha$ small reductions in J will improve welfare. However, it does not necessarily mean that going all the way back to autarky is preferred as there are levels of $J > J^*$ where $U_{ss}(J) > U_{ss}(1)$. So very large reductions in J may overshoot the maximum point to an extent which actually reduces welfare. But once J becomes very large (at the right end of the figure) any reduction in J, large or small, will improve welfare.

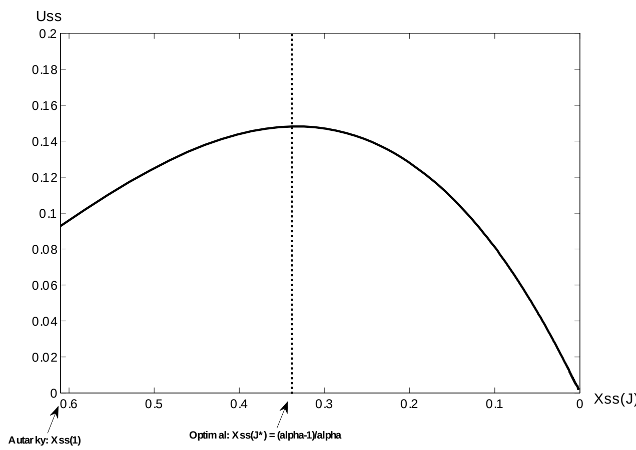

Figure 4: Solid line: U_{ss} as a function of x_{ss} which in itself is a function of J. Dashed line: the endogenous stock which in steady yields the highest utility.

3 Natural disasters

We will now analyze the effects of shocks to the stocks $\{x_i\}$. In practice they may emanate from any type of natural disaster such as a flood, a storm, a wildfire or a disease that exterminates part of the stock. Firstly, we analyze the observable reactions of the economy to a shock. That is, the dynamic effect on harvest and prices in countries hit by the shock as well as countries not directly affected. Then we evaluate welfare.

To analyze the shocks, stock asymmetries will be considered. Denote by x_i the stock in the single country i and by x_j the stock in another country. Combining (2) and (6) we get the harvest in country i as a function of its own stock and the stock of its trading partners

$$H_i = (\theta A)^{\frac{1}{1-\theta}} \left[\frac{\int_0^J x_j^{\frac{\theta q}{\theta - q}} dj}{x_i^{\frac{\theta q}{\theta - q}}} \right]^{\frac{1}{\theta-1}\frac{1-q}{q}} x_i^{\frac{\theta}{\theta-1}}. \tag{12}$$

An idiosyncratic shock to country i, when starting from the symmetric steady-state with $x_i = x_j = x_{ss}$, is represented by setting $x_i < x_{ss}$ while $x_j = x_{ss}$ for all countries $j \neq i$. A symmetric shock on the other hand would mean that $x_i = x_j < x_{ss}$ for all countries i and j.

The dynamics following a symmetric shock can be analyzed using a phase diagram of the symmetric equilibrium in the previous section (see Figure 3). Depending on the number of trade partners and on α and θ, we get either convergence back to the steady-state or collapse.

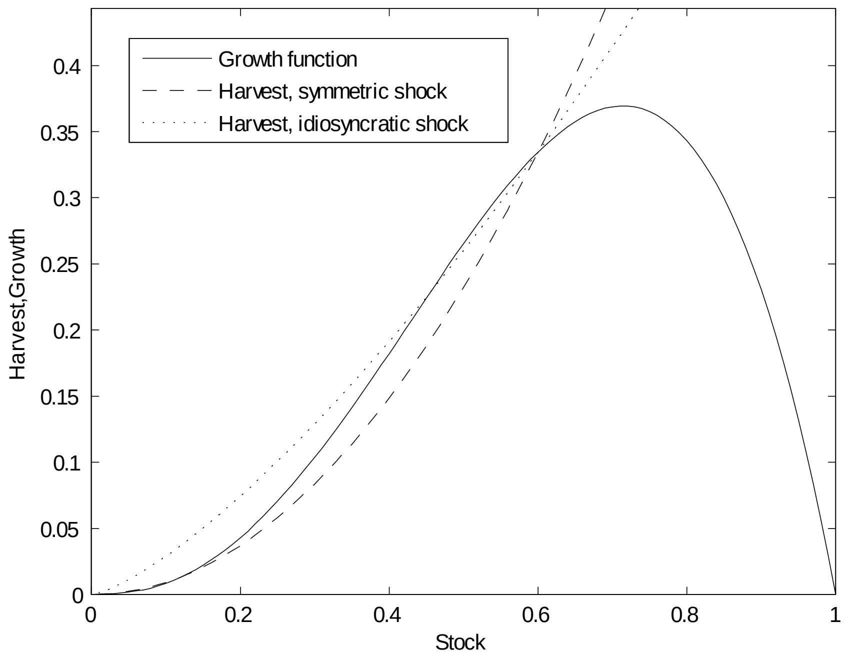

Figure 5: Phase diagram with symmetric and idiosyncratic shocks.

Now, suppose that an idiosyncratic shock hits only country i. Since each country is negligible in size, this will not affect the harvesting decisions of the other countries. Hence, starting from a steady-state, the integral in the numerator of the square bracket in (12) can be treated as a constant. The harvesting function in country i will then be proportional to $x_i^{\frac{\theta}{\theta-q}}$. In Figure 5 the ensuing harvesting decision of country i is depicted along with the harvesting decision if the shock would have been symmetric. As can be seen in this figure, if the shock is negative the harvest in country i will be strictly higher following the idiosyncratic shock compared to the symmetric shocks.

To see this analytically, equation (12) can be compared for the two alternative shocks. Since each country gives a negligible contribution to the integral, the integral will be determined by the value of $x_{\sim i}$ which denotes the stock in countries $j \neq i$. To be able to compare, suppose x_i is the same under both shock types and that under the symmetric shock $x_{\sim i} = x_i$ while under the idiosyncratic shock $x_{\sim i} \neq x_i$.

$$\nabla H_i \equiv \frac{H_i\left(x_{\sim i} \neq x_i\right)}{H_i\left(x_{\sim i} = x_i\right)} = \left[\frac{Jx_{\sim i}^{\frac{q\theta}{\theta-q}}}{Jx_i^{\frac{q\theta}{\theta-q}}}\right]^{\frac{1}{q}\frac{1-q}{\theta-1}} = \left(\frac{x_{\sim i}}{x_i}\right)^{\frac{(1-q)\theta}{(\theta-q)(\theta-1)}}$$

Here $\nabla H_i > 1$ if and only if $x_i < x_{\sim i}$.[9] Over time the stocks will change dynamically under both shocks according to the phase diagram in Figure 5. This gives us the following proposition.

Proposition 2 *1. The price of the good from country i, following a negative shock to the stock, is higher for any $x_i(t)$ if the shock is idiosyncratic than if the shock is symmetric.*

2. *Thus, for any given $x(t) \neq x_{ss}$ and negative shock size, harvest is higher under an idiosyncratic shock than a symmetric shock.*

3. *Thus, convergence back to steady-state following a negative shock is slower if the shock is idiosyncratic.*

4. *The shock size necessary to induce bio-economic collapse is strictly smaller if the shock is idiosyncratic than if the shock is symmetric.*

5. *There exists a J such that the steady-state is unstable for any negative idiosyncratic shock but stable for a symmetric shock of limited size.*

Proof. *See appendix.* ■

The first result of the proposition highlights the blessing of trade when one country is hit by a negative shock while the others are not. The lower supply of one's own products raises the world price which is a form of immediate insurance. This effect is, however, also a curse in disguise as it implies some severe complications when looking at the dynamic aspects. Under open access, the higher price induces higher harvesting effort and thus a slower convergence back to the steady-state. So while agents are better off for any given size of the stock following an idiosyncratic shock when trading, this combination ensures that they are left in a bad situation with a low stock for longer – recovery is slower.

Considering the risk of collapse, idiosyncratic shocks are more problematic than symmetric shocks in at least two ways. Firstly, the possibility of collapse arises for a larger range of α-values. There is a risk of collapse when $x = 0$ constitutes a stable steady-state. In the case of symmetric shocks, this happens when $\alpha > \frac{\theta}{\theta-1}$ while for idiosyncratic shocks, this happens when $\alpha > \frac{\theta}{\theta-q}$, where $\frac{\theta}{\theta-q} < \frac{\theta}{\theta-1}$. Secondly, the higher harvesting effort under an idiosyncratic shock also implies that smaller shocks are needed for the bio-economic system to collapse. As the number of trading partners is increased a situation emerges where any idiosyncratic shock, no matter how small, will lead

[9] This follows directly from $q < 1$ and $\theta > 1$.

to collapse. This happens when trade induces an endogenous steady-state stock $x_{ss} = \frac{(\theta-q)\alpha-\theta}{(\theta-q)\alpha-q}$. At the same point countries can be resilient to large shocks if they only would be symmetric. This can be seen in Figure 5. Following the harvesting functions from the left, the asymmetric harvesting function crosses the biological growth function for a higher level of x_i. In the specific case in the figure, a substantially smaller disaster is needed to cause collapse if it is idiosyncratic instead of symmetric. Analytically, this means that the stock levels that are unstable (i.e., where the stock goes to zero) are more encompassing. Furthermore, the fact that the country is trading, increases the risk of collapse. Had it not been trading, a shock to its stock would not have led to any shifts in the relative price and, more importantly, its stock levels would not have been as close to collapse in the first place.

These results are very much in contrast to classic results from trade theory. Trade, between individuals or between countries, is normally a way of insuring against bad states. When the production of a country is hit negatively by a shock its price goes up as long as goods are differentiated. This means that recovery will be faster when there is trade since for every unit produced the country is getting a higher income which it can invest in building up its production capacity. In a case of trade with open access renewable resources this is reversed since the higher price leads to more extensive overharvesting and thus to slower recovery and it increases the risk that a shock of a certain size will lead to collapse. This is a form of the resource curse. A country reliant on resources with open access will find it hard to recover from disasters when it is trading.

The results of Proposition 2 also highlight the two forces determining total welfare. Idiosyncratic shocks imply a slower convergence back to steady-state (and a higher risk of collapse) but the price effect ensures that flow utility is higher at any given stock level. Hence, whether one is better off under symmetric than under idiosyncratic shocks is ambiguous.

Using linearization around the steady-state the relative importance of the two effects when shocks are small can be considered. We thus consider small deviations from a symmetric steady-state. Earlier, when considering an infinitesimally small country, there were no effects on the harvesting efforts in the other countries. In the upcoming analysis we will also include dynamic reactions of other countries. We will therefore consider shocks hitting a group of a non-zero measure of countries and refer to such a shock as *partial*. In order to make the analysis more transparent, suppose all countries are divided into two groups and that the stock level is the same stock for all countries within each group. Consider a mass $\check{J}$ of countries who are hit negatively by a shock and thus have a stock $\check{x}$ and another mass $\hat{J}$ of countries who are not hit and have stock $\hat{x}$. Together, these two groups make up for all countries, i.e. $\check{J} + \hat{J} = J$. We linearize around a steady-state where all countries have stock x_{ss}. Using (12), the harvests in the two groups is given by

$$\check{H} = (\theta A)^{\frac{1}{1-\theta}} \left[\frac{\check{J}\check{x}^{\frac{\theta q}{\theta - q}} + \hat{J}\hat{x}^{\frac{\theta q}{\theta - q}}}{\check{x}^{\frac{\theta q}{\theta - q}}} \right]^{\frac{1}{\theta-1}\frac{1-q}{q}} \check{x}^{\frac{\theta}{\theta-1}}$$

$$\hat{H} = (\theta A)^{\frac{1}{1-\theta}} \left[\frac{\check{J}\check{x}^{\frac{\theta q}{\theta - q}} + \hat{J}\hat{x}^{\frac{\theta q}{\theta - q}}}{\hat{x}^{\frac{\theta q}{\theta - q}}} \right]^{\frac{1}{\theta-1}\frac{1-q}{q}} \hat{x}^{\frac{\theta}{\theta-1}}.$$

From these expressions it can be seen that harvesting effort in each group is increasing in the stock of both groups. This has the important implication that the dynamic reaction in the countries not hit will increase the risk of collapse in those who *are* hit. Thus, compared to Proposition 2 where the shocked country was so small that the others did not react, now the risk of collapse increases since the other countries react by lowering their harvest (because their relative price falls) which also implies their stock will grow. This increases the price in the shocked group more, which amplifies harvest there and hence the risk of collapse.

From now on we will analyze the welfare effects of shocks small enough as to not cause collapse. We know that for $\check{x} = \hat{x} = x_{ss}$ we have that $\check{H} = \hat{H} = f(x_{ss})$. Linearizing the dynamics of the state variables around the steady-state and then linearizing the flow utility yields an approximation of the total discounted utility, integrated along the convergence back to steady-state, following a partial shock (for derivations see the appendix). The discounted utility, net of the steady-state utility, for a country hit by a small negative shock is represented by the following expression

$$\check{V}\left(\Delta\check{x}_0, \Delta\hat{x}_0\right) = \int_{t=0}^{\infty} \left(\check{U}(t) - U_{ss}\right) e^{-\rho t} dt,$$

where ρ is a discount factor. Using the linearized dynamics and the linearized utility function (see appendix) this integral can be computed explicitly.

$$\begin{aligned} \check{V} \approx V_{lin,disaster} \equiv & \frac{U_{ss}}{x_{ss}} \frac{\check{J}}{J} \left(\frac{\theta}{\theta - 1} \frac{1}{\rho - \lambda_1} - \frac{q\theta}{\theta - q} \frac{1}{\rho - \lambda_2} \right) \Delta\check{x}_0 \\ & + \frac{U_{ss}}{x_{ss}} \frac{q\theta}{\theta - q} \frac{1}{\rho - \lambda_2} \Delta\check{x}_0. \end{aligned}$$

Here x_{ss} and U_{ss} are the steady-state stock and flow utility respectively. $\Delta\check{x}_0$ is the deviation from the steady-state stock, immediately after the shock hits, in the affected group. The group not hit by the shock are initially in steady-state , i.e. $\Delta\hat{x}_0 = 0$. Finally λ_1 and λ_2 are the eigenvalues of the linearized state dynamics and they are negative in the relevant case. $V_{lin,disaster}$ can be evaluated as a function of $\check{J}$. This tells us whether a country hit by a negative shock to its stock is better off when more countries are hit too ($dV_{lin,disaster}/d\check{J} > 0$). That is, whether symmetric shocks are better than partial. It is immediate that the sign of $dV_{lin,disaster}/d\check{J}$ is determined by the factor

$$\frac{\theta}{\theta-1}\frac{1}{\rho-\lambda_1} - \frac{q\theta}{\theta-q}\frac{1}{\rho-\lambda_2} = \frac{\theta^2(1-q)\left(\rho-\left[\frac{\alpha-1}{\alpha}-x_{ss}\right]\alpha k x_{ss}^{\alpha-1}\right)}{(\theta-1)(\theta-q)(\rho-\lambda_1)(\rho-\lambda_2)}.$$

The sign of this expression is the same as the sign of

$$\rho-\left[\frac{\alpha-1}{\alpha}-x_{ss}\right]\alpha k x_{ss}^{\alpha-1} \tag{13}$$

which immediately gives us the following proposition.

Proposition 3 $\frac{dV_{lin,disaster}}{d\check{J}} > 0$ *if and only if expression* (13) *is negative.*

This proposition expresses when a single country is better off when hit by a symmetric rather than a partial shock. The upside of the symmetric shock comes from the feedback that enables a faster recovery back to the steady-state. This is why low discounting is needed for the country to prefer symmetric shocks (a large ρ lowers the threshold x_{ss}). Otherwise agents only care for welfare right after the shock occurs which is higher following a partial shock due to the relative price effect. Likewise, note that $x_{ss} = \frac{\alpha-1}{\alpha}$ corresponds to the welfare maximizing number of trade partners in steady-state from Proposition 1 which is also depicted in Figure 4. So Proposition 3 shows that this same number of trade partners gives the cutoff for when a single country prefers to be part of a symmetric shock if there is little discounting.

These results also extend for a case where country i is *not* hit by the disaster but only its trade partners are. So more generally it can be said that small disasters hitting other countries are good from the point of view of country i once its stock is smaller than $(\alpha-1)/\alpha$. It is important to note that these results regard small shocks. Very large shocks to the trade partners would, roughly speaking in terms of Figure 4, imply a similar effect as over-shooting the stock which yields the maximum level of utility. For instance, if we start slightly to the right of the maximum point in Figure 4 (such that $x_{ss} < (\alpha-1)/\alpha$) and then envision a disaster making many other countries collapse, then this would clearly be worse from the point of view of counrty i than if there was no disaster.

4 Extension 1 – Cascading collapses among competitor countries

So far all countries have had a unique resource. Here this assumption will be relaxed. What we have in mind is a country i which has an open access renewable resource. But this country is not alone in producing this resource – there are other, "competitor", countries with the same resource. Suppose there is a number J of different resources. Letting I_j denote the mass of countries having a resource $j \in J$ we can define

$$X_j \equiv \left(\int_{k \in I_j} x_k^{\frac{\theta}{\theta-1}} \right)^{\frac{\theta-1}{\theta-q}}$$

which is a measure of the global stock of j.[10] Roughly speaking, this is the stock in all countries having this resource.

Now, suppose country i has a resource of type j_i. We are interested in analyzing the effects on the stock in country i (i.e., on x_i) when a natural disaster happens in other countries having the same resource (j_i). We solve explicitly for the intratemporal equilibrium under this setting in the appendix. There the following expression for harvest in country i is derived.

$$H_i = (\theta A)^{\frac{1}{1-\theta}} \left[\frac{X_{j_i}^q + \sum_{j \neq j_i} X_j^q}{X_{j_i}^q} \right]^{\frac{1}{q}\frac{1-q}{\theta-1}} x_i^{\frac{\theta}{\theta-1}} \tag{14}$$

We remain with the assumption of a continuum of countries. Hence, the stocks of other countries are independent of what happens in country i and everything except the own stock x_i can be treated as exogenous to country i. What this equation shows is that the harvest in country i is increasing in its own stock (x_i) and increasing in the measure of the stock (or productivity) of countries having a complement good ($X_{j \neq j_i}$). Our focus here is however on how a change in X_{j_i} affects H_i which in turn affects x_i through the biological growth function (8) again affecting H_i. For this purpose we will hold $X_{j \neq j_i}$ fixed.

Suppose for instance j_i represents white fish such as cod. A decrease in X_{j_i} could, for instance, follow from a disaster hiting Alaskan Pollock. The question is then what effect this will have on open access Hallibut fisheries. Alternatively, the analysis represents how a natural disaster to one whale fishery affects whaling in another part of the world. From

[10] For derivations see the appendix.

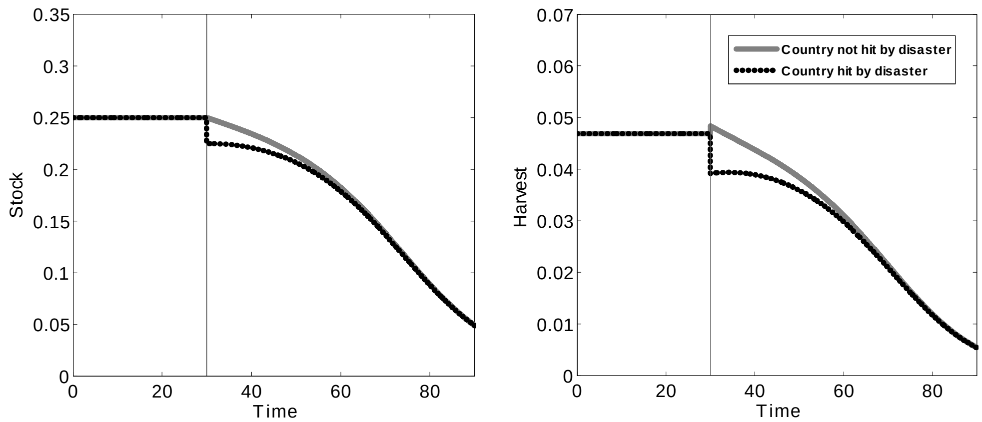

Figure 6: Example of cascading collapse. $J = 15$, $I = 2$, $\alpha = 2$. Stock in symmetric steady state is 0.25. All countries are in steady state for 30 periods. At $t = 30$ one country is hit by a disaster reducing its stock by 10%. The graphs depict the evolution of the stock and harvest in that country and in a competitor country having the same type of resource.

equation 14 it is immediate that harvest will increase in country i following a decrease in its competitors' stocks. The simple reason for this is that a decreasing stock in competitor countries lowers total supply of j_i which increases the price of resource j_i (because of the love for variety). As we have seen in earlier sections, a price increase leads to increased harvest which lowers the stock.

One detrimental such case is depicted in Figure 6. There we start in a steady state but then some of the countries having j_i are hit by a natural disaster which reduces their stock in a way that eventually leads to collapse. Then the price of good j_i goes up, which temporarily increases harvest also in country i. As x_i falls also H_i falls and collapses to zero. Hence, a natural disaster in one part of the world can trigger a chain event of collapses in countries in other parts of the world who are exporting the same resource . This result can be contrasted to the one in the model by Quaas & Requate (2013). There cascading collapse occurs as labor (fishermen) moves away from harvesting the collapsed resource to instead harvesting another resource. In our model no movements of labor are needed. Cascading collapse is purely an effect of demand pushing to over-harvest resources similar to the one already collapsed. This way trade creates a channel transforming natural disasters in one country into man-made disasters in competing countries.

5 Extension 2 – TFP increases in other countries

Next let us make the model slightly more abstract. From the harvesting function (2) it follows that, at any point in time, x_i is equivalent to a TFP factor in a production function that is linear in the amount of labor used. Given the assumption of a continuum of countries, each country is a negligible part of the total trade system and the actions of a single country will not affect the production cum harvesting decisions in other countries. Both of these observations imply that the paths of $\{x_j\}$ can be treated as independent of what happens in country i. The integral in (12) can then be treated as an exogenous factor. Defining

$$B \equiv (\theta A)^{\frac{1}{1-\theta}} \left[\int_0^J x_j^{\frac{\theta q}{\theta - q}} dj \right]^{\frac{1}{\theta-1} \frac{1-q}{q}}$$

the harvesting function in country i is

$$H_i = B x_i^{\frac{\theta}{\theta - q}}. \tag{15}$$

An increase in B can thus be interpreted as an increase in the number of trading partners or an increase in productivity of existing trade partners. The other goods may be renewable as well, but they may also be any other type of manufacturing good or commodity. We are interested in seeing how country i reacts (in terms of harvest, collapse and welfare) when production possibilities in the other countries change, as captured by changes in B. Our interpretation here is that an increase in B represents an increase in total factor productivity (TFP) in the other countries following, for instance, an increase in capital or technology for manufacturing or improved property rights for renewable resources in countries who were overharvesting before.[11] We will first analyze utility in steady-state and then discounted dynamic utility when going from one steady-state to the next.

In a steady-state, H_i from equation (15) equals f_i in equation (8). The steady-state stock is decreasing in B since an increase in B shifts the harvest function upwards as can be seen in (15). From Lemma 1 we know that steady-state flow utility is increasing in the steady-state value of N. The effects of changes in B on the steady-state harvest and flow utility will thus, as before, only depend on the biological growth function and the steady-state stock x_{ss}. An increase in B will result in an increase in steady-state harvest if and only if $x_{ss} > \frac{\alpha}{\alpha+1}$ and result in an increase in steady-state flow utility if and only if $x_{ss} > \frac{\alpha-1}{\alpha}$. This is similar to

[11] In terms of our model, going from open access to well defined property rights increases harvest in countries if they were earlier harvesting such that $x_j < \alpha / (\alpha + 1)$.

the dynamics in Proposition 1 and can therefore be graphically depicted using Figure 3. Following a permanent shift in B, a new steady-state is reached.[12] If, on the other hand the TFP increase comes in the form of a temporary shock the stock may collapse as well. For a given level of TFP there is a region of the stock which will yield collapse. This region can be reached either by a natural disaster to the own country or by a temporary and positive TFP shock in other countries. The latter increases harvest and lowers the stock in country i to the region where it cannot recover even if TFP goes back to the initial values in the other countries. In this sense a natural disaster and a positive TFP shock in other countries (if permanent or temporary) will have similar effects of increasing harvest and enhancing the risk of collapse.

What is the effect on discounted dynamic utility following a change in TFP in other countries? The harvesting effort is

$$N = Bx^{\frac{q}{\theta-q}}$$

and since flow utility is increasing in induced effort (see Lemma 1), flow utility is increasing in both B and x. An increase in B will thus always have an immediate positive effect on flow utility. Over time the stock will decrease and the net effect on the flow utility can be ambiguous. If an increase in B also lead to an increase in steady-state flow utility, the total effect is of course unambiguously positive. If, instead, the steady-state flow utility decreases, there will be a trade-off between the short run gain and long run loss. Considering small changes in B we can, again, compute the total discounted welfare effect using linearization. This will represent the discounted flow utility when going from one steady-state to the next and is therefore also representative of discounted welfare following an increase in J. Let the initial level of B be B_0, the resulting steady-state be $x_i = x_{ss,0}$ and the associated flow utility be $U_{ss,0}$. The value of B then changes to $B_0 + \Delta B$. Based on the harvest function (15) the linearized dynamics can be derived. One important difference here compared to before is that following the permanent change in B the resource stock x_i will go to a new steady-state value $x_{ss,1}$. Linearizing the flow utility around $x_{ss,0}$ an (approximate) expression for the discounted flow utility can be derived

$$\begin{aligned} V &= \int_{t=0}^{t} U(t)e^{-\rho t}dt \\ &\approx V_{lin,TFP} \equiv \frac{1}{\rho}U_{ss,0} + \frac{\theta}{\rho}U_{ss,0}\frac{\rho - \alpha k x_{ss,0}^{\alpha-1}\left(\frac{\alpha-1}{\alpha} - x_{ss,0}\right)}{\rho - \left(f'(x_{ss,0}) - \frac{\theta}{\theta-q}\frac{f(x_{ss,0})}{x_{ss,0}}\right)}\frac{\Delta B}{B_0}. \end{aligned}$$

[12] This new steady-state may have $x_i = 0$ if the change in B induces collapse.

The first term is equal to the flow utility that would result from remaining in the initial steady-state forever. The second term represents the total discounted welfare effects of the change in B. The denominator is positive whenever the initial steady-state is stable. The sign of the welfare effect of changing B therefore is the same as the sign of

$$\left(\rho - \alpha k x_{ss}^{\alpha-1}\left(\frac{\alpha-1}{\alpha} - x_{ss}\right)\right)\frac{\Delta B}{B_0}$$

which immediately leads to the following proposition.

Proposition 4 *$V_{lin,TFP}$ is increasing in ΔB if and only if*

$$\rho - \alpha k x_{ss}^{\alpha-1}\left(\frac{\alpha-1}{\alpha} - x_{ss}\right) > 0.$$

As under natural disasters , a larger ρ implies positive TFP shocks to one's trade partners increases one's own welfare. This simply reflects that the TFP increases welfare in the short run through increased prices. But if $\rho \to 0$, the sign of the welfare effect is the same as $x_{ss} - \frac{\alpha-1}{\alpha}$. This reflects that when discounting goes to zero the total effect is completely determined by the resulting change in steady-state flow utility. The cutoff for when TFP shocks for one's partners are good for oneself is hence the same as when symmetric natural disasters are preferred over idiosyncratic ones (in Proposition 3) and the same as when trade reduces steady-state welfare (in Proposition 1) and as is depicted in Figure 4.

As before, we need to qualify these results – they hold only under sufficiently small TFP shocks. Roughly speaking, in terms of Figure 4, if $x_{ss,0}$ is just below $(\alpha-1)/\alpha$, a very large permanent reduction to the trade partners' TFP would imply a new $x_{ss,1}$ which yields a lower U_{ss}. However, if $x_{ss,0}$ is sufficiently small (i.e. when trade is very extensive) then also very large reductions in the trade partners' TFP would be good as $U_{ss}(x_{ss,0}) < U_{ss}(x_{ss,1})$ for any $x_{ss,1} > x_{ss,0}$.

6 Concluding remarks

This paper has shown that trade may be harmful to countries with open access renewable resources. Essentially, when property rights are not defined properly, the individual harvester does not take the future into account when harvesting. By introducing trade, the individual gets access to a broader variety of goods, which in itself increases welfare. However, when the relative value of consumption to leisure increases, the individual is willing to exert more effort to increase the income. When taken to the aggregate level, the stock therefore falls which may lead to a lower income and potentially also lower welfare.

The dynamics of open access also reverses the result that trade normally expedites recovery of countries hit by disasters. When there is open access, recovery is slower and hence economic repercussions following natural disasters is increased by trade which also facilitates bio-economic collapse following small idiosyncratic shocks.

Finally, we generalized the model to account for a case where the trading partners are selling, not a renewable resource, but rather some manufacturing goods such as shoes, tables or cars. Here we find that positive TFP shocks to one's trade partners can cause collapse to the renewable resource and may overall be welfare decreasing to a country with open access renewable resources.

One overarching result is that the commonly used logistic growth function leads to rather exotic results in this model setting. The logistic case is the only one where trade unambiguously improves welfare and where idiosyncratic disasters are always preferred over symmetric shocks. If the regenerative power of the resource is the slightest depensational then extensive trade openness and idiosyncratic shocks are a troublesome combination. Recent empirical research on fisheries indeed suggests that the depensation case is present for many fish populations (e.g. Keith & Hutchings, 2012; Neubauer, 2013). Furthermore, with a modest and realistic extension the main results of collapse and decreasing welfare in trade openness would extend also to the logistic case. A number of empirical paper have shown that the catchability of many resources exhibit decreasing returns with regard to the stock size (e.g. Grafton et al., 2007; Kronbak, 2005; Bjørndal & Conrad, 1987). Then the logistic case enables bio-economic collapse under both idiosyncratic and symmetric.

A Derivations and proofs

Under construction

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