Land Access and its Impact on Traditional Ecological Knowledge: Modelling Knowledge and Harvest Sharing in Indigenous Communities

by

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A Thesis Submitted in Partial Fulfillment of the Requirements for the
Degree of Bachelor of Arts, Honours
in the Department of Economics
University of Victoria
April 2017

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Abstract

This paper investigates how reduced access to traditional land impacts the culture of community harvest and knowledge sharing and Traditional Ecological Knowledge of Indigenous groups. This is achieved through an analytical model based on community formation from facing risk and the associated incentive-compatibility conditions. Numerical simulations are used to highlight long term effects of losing land-based services. The model shows how a single reduction in land results in a breakdown of community structure and a loss in the stock of traditional knowledge. Furthermore, a single reduction in land past a threshold value of land base loss can catalyze a downward spiral resulting in the complete breakdown of the community.

Special Thanks This paper was written as a visitor on the traditional territory of the WS'ANEC', Lkwungen, and Wyomilth peoples of the Coast Salish Nation.

In Peter's words, “A research project is a journey of discovery. As a new adventurer, one is best to follow a guide, to be sure there is a destination, and a manageable route to it. With experience, you develop the skills to set your own destination, and choose your own route, and that is the fun of it, even if you get hopelessly lost along the way.” I definitely had fun and got lost multiple times. Thank you Peter and Donna for helping me reach my destination, being patient while I learned new skills, and inspiring me. This project would not exist without you.

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1. Introduction

This paper provides an analytical model to better understand the impact of a reduction in traditional land base on the structure of an Indigenous community and its Traditional Ecological Knowledge. Many Indigenous peoples have a strong connection with their traditional lands and territories (OHCHR, 2013). This integral relationship Indigenous groups have with their natural environment is embodied in the Traditional Ecological Knowledge (TEK) of their community. This form of knowledge encompasses traditional knowledge, practices, and beliefs pertaining to a specific locality, and its associated natural resources, such as local flora and fauna (Berkes et al., 2000). Livelihoods of Indigenous communities depend on the quality of land, combined with TEK, for exploiting the services the land provides, like hunting, collecting materials, and harvesting medicinal plants (Berkes et al., 2000). Transmitted culturally, TEK is gained through physical interaction with the land (Berkes et al., 2000). These interactions contribute to the accumulation of the stock of traditional knowledge within a community.

Indigenous peoples have shared histories of "removal from traditional lands and territories, subjugation, destruction of their cultures, discrimination and widespread violations of their human rights" (OHCHR, 2013). As traditional territories of various Indigenous groups are reduced and degraded, traditional knowledge, practices, and community welfare are inevitably affected. Other disciplines have explored the multifaceted impacts of land loss on traditional knowledge, such as social, cultural, ecological, and economic impacts. While some studies have examined Indigenous groups functioning as farming co-operatives sharing risk (Greg, 2009), no economic literature to date has modeled the effects of land loss or environmental degradation on the long-term viability of Indigenous communities and TEK.

In this paper I investigate how reduced access to traditional land leads to a breakdown in the culture of community harvest and knowledge sharing, and the associated maintenance of traditional knowledge. I extend this analysis to explore the impacts of initial land loss on long-term community stability. While many factors affect TEK and the welfare of Indigenous communities, this paper solely focuses on the reduction of land base of traditional territories.

I examine these issues in the context of a model where TEK is a stock of knowledge that is used as an input, in combination with the land, to provide productive services. Sharing within the community is motivated by risk pooling as individuals face a stochastic production process. Risk pooling in turn induces a problem of moral hazard, as individual consumption is dependent on group output. For community members to exert effort the community sharing regime must be incentive-compatible. Furthermore, sharing within the community facilitates knowledge transmission between members. The key results of the paper arise through the impact of losing land-based services on the incentive-compatibility of the culture, and the associated stability of the community.

The model shows how a single reduction in land quality or quantity can result in a breakdown of community structure and a loss in the stock of traditional knowledge. Further, this single reduction in land can catalyze a downward spiral resulting in the complete breakdown of the community.

These findings have multiple policy dimensions, including potential implications for cultural revitalization and environmental impact assessments. As a contribution to the process of reconciliation in Canada, it is important for economists to acknowledge and engage in these issues (Feir & Hancock, 2016).

The paper is structured as follows. Section 2 highlights related literature, and the gap this paper aims to fill. Section 3 describes the model characteristics and underlying assumptions. Section 4 considers the payoffs of an agent in autarky, and outside options away from traditional territories. Section 5 explores risk-pooling with full communal sharing, and the associated incentive-compatibility and individual-rationality conditions in equilibrium for a stable community. Section 6 extends this analysis to a partial sharing regime. Section 7 outlines the results of numerical land loss simulations. Section 8 provides a discussion on the model's limitations. Section 9 speaks to further research and policy implications, and Section 10 provides concluding remarks.

2. Literature Review

A large literature exists on Traditional Ecological Knowledge (TEK) and it permeates several disciplines. While there is no universal definition for TEK, the fundamental characteristics associated with this way of knowing are explored below.

TEK accumulates over many generations of Indigenous societies, whose existence depends on the use of this knowledge through direct interaction with the environment in a specific geographic area (Berkes, 1993; Berkes et al., 2000)). It is a "cumulative body of knowledge, practice and beliefs", that is dynamic and adapts as environments and societies evolve over time (Berkes, 1993; Berkes et al., 2000). TEK is culturally transmitted, passed down in oral tradition, or shared amongst resource users (Huntington, 2000).

Indigenous societies that rely on direct use of natural resources and land have a critical dependence on TEK to be productive in hunting, gathering, and other sustenance-providing activities (Berkes, 1993). The knowledge of a community becomes embedded in the practices of everyday life, in institutions, and in social norms (Berkes et al., 2000). Additionally, the TEK held within a community provides the community with a distinct culture and identity, spiritual values, stewardship, an intergenerational perspective, and a connection with the natural environment (Berkes, 1993). In a social context, TEK pertains to oral histories and spiritual relationships, worldviews, and “relations based on reciprocity and obligations towards both community members and other beings and communal resource management” (Berkes, 1993).

TEK is similar to Western science in that they are both “ways of knowing” through an accumulation of observations; however, the two differ in terms of fundamental underlying principles (Berkes et al., 2000). For the most part, TEK is qualitative (with an empirical basis), holistic and spiritual, based on an accumulation of facts from experiential trial and error, and concerns long-term information about a specific locality (Berkes, 1993).

TEK is important not only for the livelihood and identity of individual communities, but for its plethora of other uses to society more generally. The preservation of TEK can be used for biological and medicinal insights, resource management, conservation, and land use planning and assessments (Berkes, 1993). Moreover, preserving cultural diversity through the maintenance of TEK in different communities contributes to the conservation of biodiversity and ecological processes of the environment to which the knowledge pertains (Berkes et al., 2000).

There have been various environmental and socioeconomic factors that have contributed to the erosion of knowledge held in communities, including changes in land use and loss of access to natural resources (Gómez-Baggethun et al., 2013). Elevated rates of environmental change have also resulted in the stock of TEK in the majority of Indigenous communities to decline (Turner et al., 2000). Sufficient levels of sovereignty over land and ecological means of production have been shown to be essential for knowledge generation and transmission (Gómez-Baggethun & Reyes-García, 2013).

It is important to recognize that Indigenous people are unique and diverse, as are the practices and knowledge of different groups (Turner et al., 2000). Nonetheless, evidence suggests that sharing plays an important role in many Indigenous societies. These societies have traditionally consisted of subsistence producers facing environmental uncertainty, and successful food harvesting has not always been guaranteed (Carlos & Lewis, 2016). As food supply is variable, communities aggregate harvests and redistribute them among community members (Carlos & Lewis, 2016). This reciprocity and redistribution is a form of repeated gift-giving among individuals, serving as a form of informal insurance and minimization of risk (Carlos & Lewis, 2016). The uncertainty of the environment motivates the community culture to share, which in turn has proved to be essential to survival. Societal norms provide an incentive to reciprocate (Carlos & Lewis, 2016). This informal insurance mechanism has been discussed in various disciplines, and there is a well-established economic literature concerning risk pooling, group formation, and informal insurance in low-income, agricultural, or subsistence economies (Genicot & Ray, 2003; Ligon et al., 2002; Zeller, 1998). Within this literature, some studies address Indigenous communities specifically. For example, Greg (2009) explores Indigenous farming cooperatives and informal arrangements among risk-averse households of the North Carolina Cherokees.

Furthermore, harvest and redistribution practices facilitate knowledge transmission. Ohmagari and Berkes (1997), in their ethnographic study of Western James Bay Cree peoples, state that “subsistence is not merely a way of obtaining food but also a way of life and a mode of production that sustains social relationships and distinctive cultural characteristics of a society.”

Communities living in close relationship with the land exhibit sharing as part of their community structure and associated institutions. Furthermore, Ohmagari and Berkes (1997) argue that the decline in trapping as an act of food harvesting leads to a decline in hands-on experience for younger community members, and ultimately a decrease in knowledge transmission. With the decline of their traditional modes of learning, apprenticing on the land, and observing, rates of skill and knowledge transmission have declined (Ohmagari and Berkes, 1997).

For example, the sharing system of the Copper Inuit people in Northern Canada is fundamental for maintaining community cohesion (Collings et al., 1998). The *piqatigiit*, a seal sharing partnership system, was considered an integral form of Inuit sharing before its disappearance (Collings et al., 1998). Sharing is essential in social practices and central to cultural identity (Collings et al., 1998). The distribution system was possible because of ecological and intergenerational relations (Collings et al., 1998).

For Indigenous communities, traditional lands are essential for this transmission of knowledge. As previously mentioned, an adequate land base is required for subsistence learning activities to take place, activities that facilitate knowledge transmission to other community members. Long-term repetition of this lifestyle of subsistence transfers knowledge, values, and culture (Ohmagari & Berkes, 1997).

Furthermore, the relationship between the environment and knowledge transmission is deepened with an adequate and somewhat reliable land base. Nunn and Giuliano (2017), in their study of traditional languages, find that Indigenous groups with histories of environmental instability are less likely to have younger generations continuing cultural practices. Conversely, populations living in environments which are stable over many generations are more likely to have their traditions practiced by younger generations, as the similarity of the environment over time makes the transmitted knowledge more applicable to the locality, and hence more value is placed on traditional knowledge (Nunn & Giuliano, 2017). Drastic changes to the land base lessen the likelihood for traditional knowledge to be transmitted, utilized, and maintained over time.

The collective TEK of a community can be considered a form of cultural capital. This capital binds community members together through knowledge and social and institutional capital (Berkes & Folke, 1994). Cultural capital includes factors that “provide human societies with the means and adaptations to deal with the natural environment and to actively modify it” (Berkes & Folke, 1994, p.130). Berkes and Folke (1994) provide examples of cultural capital as the interface between natural and human capital, including societal and political institutions, environmental ethics and worldviews, and TEK held in communities (Berkes & Folke, 1994). Cultural capital is developed in societies and “implies commonality, providing a basis for a collective action within that group” including the governance of resource use and interactions with the natural environment (Berkes & Folke, 1994, p.130-131). TEK affects how Indigenous communities interact with, manage, and adapt to their natural environment. This form of cultural capital accumulates within the community and continues to influence the actions of its members, forming their worldviews, institutions, and values.

My paper attempts to integrate these interpretations of TEK from the existing literature into a simple analytical model that allows an investigation of the relationship between lands, TEK and community structure through an economic lens.

3. Model Overview

The model encapsulates an Indigenous community and its associated traditional lands. I use this simple model to determine the long run equilibrium with respect to communal sharing, TEK, and community size. By modeling an Indigenous group that is functioning together in equilibrium, we can examine the consequences of land loss on community viability.

3.1 Indigenous Community

The Indigenous community is composed of n members, all homogeneous except with respect to their outside options, all risk-averse and all facing the same production process. Individuals cannot join a community but they can leave for their outside option. The community generates outputs such as food, materials, or medicines, through interactions with their traditional territory. Each community member is capable of participating in productive activities on the land, although there is no reprimand for neglecting to do so. Furthermore, communities practice some degree of communal sharing in terms of harvest and knowledge. A sharing rule determines the level of sharing. The fraction of the harvest shared is denoted by s. Full sharing – individuals contributing their entire harvest to the communal bundle – corresponds to $s = 1$ and partial sharing is represented by $s < 1$.

3.2 Traditional Land

The traditional land of a community is a specific locality used and managed by the group over a long period of time. I represent the overall quantity and quality of land by an index denoted by L_t. The quantity of land is the geographic area of the traditional territories while the quality of land is a measure that reflects enhancements or diminutions in the productivity of the land, such as levels of degradation, biodiversity, or contamination. Nothing is lost by combining these two dimensions of land into a single index since they conceptually play the same role in the model.

3.3 Traditional Knowledge

Traditional knowledge is knowledge concerning a specific environment. It is a stock variable used as an input to productivity on the land, denoted by K_t. This form of knowledge is unique in that it is not documented conventionally through writing. Knowledge is acquired through individual experience by direct interaction on traditional lands, and through the sharing of those experiences with others. The stock of knowledge accumulates over time, transmitted through oral communication.

An example of how knowledge may be accumulated is community members coming together after a day of harvesting to share the products of their harvest and share their stories. As the harvest is shared, experiences are shared, and knowledge of the land accumulates, making the community more productive.

The generation of knowledge in one period depends on the knowledge held in the previous period and the experiential learning within the community. The knowledge production process is represented as follows:

$$K_{t+1} = K_t^{\alpha} E_t^{\beta} \tag{1}$$

where K_t is knowledge in period t, E_t is shared experiential learning in period t, and $\alpha \in [0,1]$ and $\beta \in [0,1]$ are parameters. Knowledge and experiential learning can be normalized such that $K_t \in [0,1]$ and $E_t \in [0,1]$.

A community's stock of knowledge can increase or decrease over time depending on the amount of shared experiential learning. In particular, if $E_t = E \; \forall \; t$ then the explicit solution to (1) is:

$$K_t = K_0^{A(t)} E^{\beta(t)} \tag{2}$$

where:

$$A(t) = \alpha^t \tag{3}$$

and:

$$B(t) = \frac{\beta(1 - \alpha^t)}{1 - \alpha} \tag{4}$$

Setting $K_{t+1} = K_t = K_{SS}$ in (1) and solving for K_{SS} yields the steady state value:

$$K_{SS} = E^{\frac{\beta}{1-\alpha}} \tag{5}$$

For $K_{SS} = 1$, designated as "full knowledge", it is necessary that $E = 1$, designated as "full learning". For any value of E less than one, K_{SS} will be less than one.

If $K_{SS} \neq K_0$ then K_t converges towards K_{SS}, where the direction of convergence depends on the size of E relative to $\bar{E}$, where:

$$\bar{E} = K_0^{\frac{1-\alpha}{\beta}} \tag{6}$$

If $E < \bar{E}$ then $K_{SS} < K_0$ and K_t falls over time towards K_{SS}. If $E > \bar{E}$ then $K_{SS} > K_0$ and K_t rises over time towards K_{SS}. If $E = \bar{E}$ then $K_{SS} = K_0$ and K_t remains constant over time

Individuals learn from their own experiences and from the shared experiences of others. Thus, learning among community members depends on the extent of sharing and the number of individuals participating relative to the initial community size. Shared experiential learning in a given period is expressed as:

$$E_t = s_t^{\gamma}(\frac{n_t}{n_0})^{\delta} \tag{7}$$

where s_t is the degree of sharing in the community in period t, n_0 is the initial size of the community determined historically, n_t is the current community size, and $\gamma \in [0,1]$ and $\delta \in [0,1]$ are parameters . E_t is increasing in s_t because greater sharing means more interaction among community members, and hence, greater opportunities for the sharing of stories and experiences. Similarly, E_t is increasing in n_t because a larger and more diverse set of experiences are shared within the community (in the same way that a larger sample size conveys greater information than a small sample size). Expressing this effect in terms of n_t/n_0 normalizes experiential learning to be $E_0 = 1$ in an historically stable community with full sharing. Note also that expression (7) tells us that a stable population with full sharing also has full learning, and so $K_{SS} = 1$ for that community.

3.4 Outputs from Traditional Land and Knowledge

A community member can apply their traditional knowledge directly to the land to produce output. I refer to this production process as the “harvest process”. Production in any given period is a function of inputs L and K in that period. I assume limited substitutability between the two inputs because output requires both land and knowledge. An abundant amount of knowledge is meaningless without at least some land on which to apply that knowledge, and a large area of land is unproductive without the associated traditional knowledge of the environment.

Consider hunting as one example of a harvest process. This process is depicted in Figure 1 as a simple game tree, where a community member faces a choice over hunting effort. In the first stage of the game, the agent faces a binary decision over whether to exert effort $(e = 1)$, or to not exert effort $(e = 0)$. If the agent chooses not to exert effort, then with certainty they will have an unproductive hunt $(z = 0)$. In the second stage of the game, nature plays. This introduces a stochastic element into the harvest process. The randomness of the hunt creates uncertainty as to whether or not the agent will be successful. Exerting effort, there is probability p that the agent will have a successful hunt $(z = 1)$, and probability $(1 - p)$ that the agent will have an unsuccessful hunt $(z = 0)$. Thus, there are three possible outcomes in this game: no effort and no harvest; effort with successful harvest; effort with unsuccessful harvest.

3.5 Probability of Success

The probability of success when exerting effort is a function of land and knowledge in the current period. A community member is more likely to have a successful hunt if they have greater traditional knowledge of the area, and a greater value of the land index will also lead to a higher probability of success. In particular, the probability of an individual having a successful harvest when exerting effort is:

$$p_t = 1 - \frac{\theta}{\theta + K_t^{\alpha} L_t^{\beta}} \tag{8}$$

where K_t is traditional knowledge, L_t is traditional land, and $\theta > 0$, $\alpha \in [0,1]$ and $\beta \in [0,1]$ are parameters. The lower bound on p is zero.

In a community with sharing, consumption by any agent will also depend on the harvest outcomes of all other community members. I make the simplifying assumption that all hunting outcomes are independent. Thus, if x denotes the number of successes among the other $n-1$ community members, then $P_t(x)$ has a Binomial distribution and can be expressed as:

$$P_t(x) = \frac{p_t^x (1-p_t)^{n-1-x} (n-1)}{x!\,(n-1-x)!} \tag{9}$$

3.6 Utility and Consumption

A community member's preferences are represented by the following utility function:

$$u = \ln(1+c) - \psi e \tag{10}$$

where c is the agent's individual consumption, e is the binary level of effort exerted, and ψ is the disutility of exerting effort. Community members will maximize their expected utility with respect to the stochastic production process. However, the magnitude of individual consumption varies depending on the degree of sharing within the community. For example, with minimal sharing, consumption depends heavily on individual harvest success. With substantial sharing, consumption is less dependent on the individual's harvest and more dependent on the successes of the other community members. I consider three scenarios with respect to sharing, beginning with no sharing (autarky) in the next section.

4. Autarky

4.1 Autarky Payoffs

In autarky, the agent is effectively an independent individual outside of a community, applying their knowledge on the land. Consequently, their consumption is a direct result of their own harvest process. Individual consumption can be represented as follows:

$$c_{e,z} = ez\omega \tag{11}$$

where e denotes the binary value for effort, z denotes the binary value for a successful or unsuccessful harvest and ω is a parameter denoting units of harvest (i.e. kilograms). Similarly, utility can be expressed in terms of effort and harvest outcome:

$$u_{e,z} = \ln(1 + c_{e,z}) - \psi e \tag{12}$$

Facing the stochastic production process, there are three possible levels of utility in autarky:

$$u_{0,0} = 0 \tag{13}$$

$$u_{1,0} = -\psi \tag{14}$$

$$u_{1,1} = \ln(1 + \omega) - \psi \tag{15}$$

4.2 Autarky Choices

The individual must choose whether or not to exert effort. The payoff associated with not exerting effort is zero with certainty. The expected payoff associated with exerting effort is:

$$V1_A = p \ln(1 + \omega) - \psi \tag{16}$$

The agent will exert effort ($e = 1$) in autarky if and only if the expected payoff associated with exerting effort is greater than or equal to zero ($V1_A \geq 0$), and so there exists a threshold value of p above which the agent will decide to exert effort. Setting $V1_A = 0$ and solving for p yields this threshold value, denoted as $\bar{p}$:

$$\bar{p} = \frac{\psi}{\ln(1+\omega)} \tag{17}$$

If $p \geq \bar{p}$ then the agent will exert effort but not otherwise.

This threshold condition on exerting effort can also be expressed in terms of K and L. In particular, equating p to $\bar{p}$ and solving for K yields a critical value $\overline{K}$, below which effort is not worthwhile. Plotting $\overline{K}$ in (L, K) space partitions the space into two regions: where $e = 1$ and $e = 0$ (see Figure 2). Low levels of K and L induce no effort, as these low levels negatively affect the probability of success. Similarly, high levels of K and L induce effort as they correspond to a high probability of a successful harvest.

4.3 Autarky with Outside Options

The agent may also have an outside option, providing an alternative to remaining on the land. In that case, a positive payoff to exerting effort may not be enough to induce that effort; the outside option may be preferable. I do not investigate this possibility here but instead delay consideration of outside options until the modeling of community sharing, where the outside options available will be critical determinants of community structure.

5. Full Sharing

Facing a stochastic harvest process, uncertainty is high for an individual in autarky. Individuals may instead come together in a community and share their harvest to decrease harvest uncertainty, as a form of insurance to smooth variability in consumption for agents. That is, the stochastic nature of production is a motivation for risk-pooling among agents.

However, sharing also creates moral hazard by weakening the link between effort and payoff. For a community to form where all members continue to exert effort, the sharing rule must be incentive-compatible, and individually rational. That is, the sharing rule must induce an equilibrium in which each community member prefers to exert effort over not exerting effort, given that everyone else is exerting effort, and each member must prefer to be in the community over the outside option. These two conditions must be satisfied for the community to function with sharing.

In this section I examine the conditions required to support *full sharing* as an equilibrium outcome. Under a full sharing regime all group members contribute their entire harvest to an aggregate supply, which is then distributed equally amongst community members.

5.1 Full Sharing Payoffs

To illustrate the potential outcomes under full sharing, consider the incentives of a single community member, agent j. Agent j's consumption is a function of their individual harvest, and the harvest of $n-1$ other community members. In particular, if all other members of the community exert effort then consumption by agent *j* is:

$$c_j = \frac{e_j z_j \omega + x\omega}{n} \tag{18}$$

where e_j is the binary effort value for agent j, z_j is the binary success value for agent j, and x denotes aggregate number of successes among all other agents in the community.

For any given realization of x, there are three possible outcomes for agent j: no effort; unsuccessful effort; and successful effort. Using the same notation for utility as in (12), the three associated payoffs are:

$$u_{j0,0} = \ln(1 + \tfrac{\omega x}{n}) \tag{19}$$

$$u_{j1,0} = \ln(1 + \frac{\omega x}{n}) - \psi \tag{20}$$

$$u_{j1,1} = \ln(1 + \frac{\omega + \omega x}{n}) - \psi \tag{21}$$

The realized payoff for agent j from exerting effort is a function of two random variables: their own harvest outcome; and the harvest outcomes of other members of the community. Recall that the probability of success for an individual agent is p_t, given by (8), while the probability of x collective successes from the $n-1$ other agents is $P_t(x)$, given by (9). Thus, the expected payoff to agent j from exerting effort is:

$$V1 = p_t\left(\sum_{x=0}^{n-1} P_t(x) \ln\left(1 + \frac{\omega + \omega x}{n}\right)\right) + (1 - p_t)\left(\sum_{x=0}^{n-1} P_t(x) \ln\left(1 + \frac{\omega x}{n}\right)\right) - \psi \tag{22}$$

The expected payoff from not exerting effort is:

$$V0 = \left(\sum_{x=0}^{n-1} P_t(x) \ln\left(1 + \frac{\omega x}{n}\right)\right) \qquad (23)$$

5.2 The Incentive-Compatibility Constraint

In a rational expectations equilibrium with universal effort, incentive-compatibility requires $V1 \geq V0$ for every community member. As in autarky, the incentive-compatibility condition is characterized by a threshold value of p such that $V1 > V0$. There is no analytical solution for this critical value but its properties can be explored numerically. Figure 3 plots $(V1 - V0) = 0$ in (p, n) space; it is a locus of (p, n) pairs that constitute the incentive-compatibility threshold.

The incentive-compatibility threshold splits the space into two regions: non-incentive-compatible; and incentive-compatible. Note that the threshold is upward sloping. To understand why, consider a small community facing a high probability of a successful harvest, which corresponds to high levels of p and low values of n in Figure 3. With a small community, it is crucial that everyone exerts effort and contributes to the harvest. If an individual chooses not to exert effort, it will have a substantial impact on the aggregate community harvest, and on consumption by that individual. Moreover, given that p is high, there exists a strong incentive for community members to exert effort because they will most likely be successful. Thus, the incentive-compatibility condition is satisfied in this region.

Conversely, consider a large community facing a low probability of successful harvest. With a large community, if a single individual chooses to not exert effort, it will not have a substantial impact on the community harvest, nor on the consumption by that individual. Moreover, given that p is low, there is only a weak link between effort and success. Thus, the incentive-compatibility condition is not satisfied in this region.

5.3 Individual Rationality

Individual rationality requires the expected payoff from exerting effort in the community to be at least as great as the expected payoff from exerting effort alone in autarky or pursuing an outside option. If autarky is the only option, then individual rationality requires $V1 \geq V1_A$, where $V1$ is given by (22) and $V1_A$ is given by (16). This condition necessarily holds if the incentive-compatibility condition holds because sharing provides the benefits of risk pooling while there is no loss of effort (relative to autarky) in an incentive-compatible community.

If a community member has an outside option off the land then the payoff in autarky is no longer the relevant comparator for individual rationality, and incentive-compatibility no longer guarantees individual rationality. This more complex relationship between incentive-compatibility and individual rationality will play a pivotal role in how a community changes in response to a loss of land, and how that response can precipitate a downward spiral. In particular, recall that p is an increasing function of L. Thus, a reduction in land will result in a reduction in p, and this could potentially shift an existing community into a non-incentive-compatible region of the parameter space. A community impacted in this way may have to shrink in size or adopt a sharing rule under which the harvest is only partially shared. This in turn will change the payoff from remaining in the community, and could make the outside option more attractive, thereby causing a loss of community members. Thus, a substantial exogenous reduction in L could destabilize an existing community through its initial impact on the incentive-compatibility of that community, and then on the individual rationality conditions required to sustain that community.

I explore these possibilities in the next sections. I first examine how a change in the sharing rule can restore incentive-compatibility after a loss of land, and then examine the implications for individual rationality and the associated potential for an outflow of community members.

6. Partial Sharing

As previously discussed, if p falls below the incentive-compatibility threshold level – as a consequence of a loss of land – then the community becomes non-incentive-compatible. Incentive-compatibility can be restored via a reduction in community size or a reduction in the amount of sharing; either of these changes will incentivize effort and thereby dampen the moral hazard problem. Of course, this also reduces risk pooling within the community, thereby reducing the payoff to remaining in that community. In the Appendix I show that the *optimal* approach to restoring incentive-compatibility is to maintain the community size and reduce the amount of risk sharing. That is, in a community planning problem where the payoff to a community member is maximized subject to the incentive-compatibility constraint, the solution always requires keeping n as high as possible and reducing the amount of sharing until incentive-compatibility is achieved. We can therefore focus exclusively on a change to the sharing rule as the community response to a loss of land.

Of course, any reduction in the amount of sharing has consequences for community culture. Bringing the harvest together and sharing it amongst community members facilitates the sharing of knowledge. A reduction in sharing lowers communal interaction, reducing experiential learning and the associated accumulation of traditional knowledge. These long-term consequences of reduced sharing will play a key role if the dynamics of community decline that I explore in Section 7.

6.1 Partial Sharing Payoffs

Under a partial sharing regime, community members contribute a fraction $s < 1$ of their harvest to an aggregate bundle, which is then distributed equally amongst all members. Individuals keep the remaining fraction, $1 - s$, for their own consumption. If all other members of the community exert effort then consumption by agent *j* is:

$$c_j = \frac{s(e_j z_j \omega + x\omega)}{n} + (1 - s) z_j \omega \tag{24}$$

As in the setting with full sharing, for any given realization of *x*, there are three possible outcomes for agent *j*: no effort; unsuccessful effort; and successful effort. Using the notation from Section 5, the corresponding payoffs are:

$$u_{j0,0} = \ln(1 + \tfrac{s\omega x}{n}) \tag{25}$$

$$u_{j1,0} = \ln(1 + \frac{s\omega x}{n}) - \psi \tag{26}$$

$$u_{j1,1} = \ln(1 + \frac{s(\omega + \omega x)}{n} + (1 - s)\omega) - \psi \tag{27}$$

Following the approach from Section 5, the expected payoff to agent *j* from exerting effort is:

$$V1 = p_t \left(\sum_{x=0}^{n-1} P_t(x) \ln \left(1 + \frac{s(\omega + \omega x)}{n} + (1 - s)\omega \right) \right) + (1 - p_t) \left(\sum_{x=0}^{n-1} P_t(x) \ln \left(1 + \frac{s\omega x}{n} \right) \right) - \psi \tag{28}$$

The expected payoff from not exerting effort is:

$$V0 = \left(\sum_{x=0}^{n-1} P_t(x) \ln \left(1 + \frac{s\omega x}{n} \right) \right) \tag{29}$$

6.2 The Incentive-Compatibility Constraint

Following the method from the previous sections, I derive the incentive-compatibility condition in terms of a critical value, but now that critical value is with respect to s. Again, there is no analytical solution for this critical value but its properties can be explored numerically.

Figure 4 plots $(V1 - V0) = 0$ in (s, n) space for a given value of p. This incentive-compatibility threshold partitions the space into incentive-compatible and non-incentive-compatible regions. At high levels of n and s, moral hazard poses a substantial problem, making the community non-incentive-compatible. Conversely, in a small community with limited sharing, individuals cannot afford to shirk.

Consider the impact of a loss of land on the incentive-compatibility threshold in Figure 4. A loss of land causes a reduction in p and this causes the incentive-compatibility threshold to shift to the left. As the probability of a successful harvest falls, the incentive for individuals within the community to exert effort declines, and so the incentive-compatible region shrinks. If the reduction in p is large enough then a community can become non-incentive-compatible, and incentive-compatibility can only be restored via a reduction in s or a reduction in n or a combination of both. As discussed earlier, the optimal approach for the community is to maintain n and reduce s to restore incentive-compatibility (see the Appendix).

6.3 A Self-Reinforcing Feedback Loop

Reducing s in response to a reduction in p has important implications for the stock of traditional knowledge within the community. Recall from (1) and (7) that communal sharing facilitates knowledge transmission. If sharing is reduced, the transmission of knowledge between community members is also reduced, ultimately eroding the stock of knowledge held within the community. As p is an increasing function of K, a reduction in the stock of knowledge in turn reduces the probability of harvest success. Thus, a reduction in p from a one-time loss of land creates a self-reinforcing feedback loop, as depicted in Figure 6. This has the potential to cause a downward spiral of the community over time. The dynamics of that downward spiral are in turn determined by whether or not it remains individually rational for community members to remain in the community. They may instead choose to leave the land and seek an outside option. I explore this possibility next.

6.4 Outside Options and Individual Rationality

If the payoff to an individual from remaining in the community falls below her outside option then she has an incentive to leave the community. Modeling this response properly is complicated. Ideally, each community member should be modeled as comparing the present value of the outside option at any point in time with the expected present value of the in-community payoff at that point in time, based on a rational expectation of the future dynamics of the community. This demands considerable computational power and programming requirements that are beyond the scope of this project. Instead, I assume a simple and admittedly rigid set of rules for when a member will leave the community, that can be roughly interpreted as a consequence of frictions and adjustment costs in a more fully-specified decision process.

It is assumed each community member faces a heterogeneous outside option, and community members are ordered from $i = 1 \dots n$ with respect to their outside option, with member $i = 1$ having the lowest outside option. This outside option for member i is specified as a fraction of the payoff from staying in the *pre-disturbance* community whose population is n_0 . This fraction is:

$$w_i = \varphi \left(\frac{i}{n_0}\right)^{\eta} \tag{30}$$

where $\varphi < 1$ and η captures the extent of heterogeneity across community members. As η increases, the outside options of community members become more heterogeneous. If $\eta = 0$, all community members have the same outside option.

I assume that only one individual can leave in each time period (as a rough way of capturing frictions and adjustment costs). If the outside option in any period exceeds the in-community payoff in that period for any set of community members, then the member with the highest outside option among that set will leave the community.

7. The Impact of Land Loss: Simulation Results

Since the model cannot be solved analytically, numerical simulations are used to examine its behavior in response to an exogenous, one-time loss of land. The simulations examine changes in knowledge, sharing, probability of successful harvest, population size, experiential learning, and payoffs over a period of years.

7.1 Base Case

In the initial period before the reduction in land base ($t = 0$), the community is in a pre-disturbance state with incentive-compatible full sharing, a stable population denoted n_0, and a stable stock of knowledge normalized to $K_0 = 1$. Accordingly, there is perfect experiential learning ($E_0 = 1$). The initial land base is denoted by L_0, normalized $L_0 = 1$. The payoff to community members in this pre-disturbance state is denoted as v_0. Table 1 provides the normalized initial variable values. Table 2 provides the base parameter values assigned for the simulations. Under these initial conditions and parameter values, the implied initial probability of success is $p_0 = 0.5$. The simulations are run over 150 periods (interpreted here as years).

The fraction of land loss is denoted by q, and occurs at the beginning of period 1. Consequently, the probability of harvest success in period 1 falls to:

$$p_1 = 1 - \frac{\theta}{\theta + K_0 L_0 (1-q)} \tag{31}$$

The implications of this initial reduction in the probability of success depend critically on the size of q, and the simulations show that four distinct scenarios emerge with notably different dynamics. The thresholds separating these scenarios occur at $q_{12} = 0.200$, $q_{23} = 0.332$, and

$q_{34} = 0.641$, corresponding to land losses of 20%, 33.2% and 64.1% respectively. Figure 7 displays the magnitude of these threshold levels relative to one another.

7.2 Scenario 1

Scenario 1 occurs when $q \leq q_{12}$. This loss of land is not enough to make the full-sharing community non-incentive-compatible. Thus, sharing and knowledge are not affected, and the community stays at size n_0. However, there is a permanent reduction in p, which negatively impacts the harvest of the community, and there is an associated permanent reduction in the expected payoff. Figure 8 depicts these changes for key variables when the reduction in the land index is 10 percent ($q = 0.100$).

7.3 Scenario 2

Scenario 2 occurs when $q_{12} < q \leq q_{23}$. In this scenario the loss of land is large enough to render the community non-incentive-compatible. In response, the community reduces s and this initiates the feedback loop in which experiential learning falls, and the stock of knowledge declines over time. However, these variables do stabilize over time because the expected payoff for community members does not fall by enough to cause any members to leave. All community members are nonetheless permanently worse off and some traditional knowledge is lost. Figures 9 and 10 depict the impact on key variables under this scenario when the reduction in the land index is 30 percent ($q = 0.300$).

7.4 Scenario 3

Scenario 3 occurs when $q_{23} \leq q \leq q_{34}$. In common with Scenario 2, in this scenario the loss of land is large enough to render the community non-incentive-compatible and thereby initiate the feedback loop. However, in this case the impact on the expected payoff for community members is large enough that some individuals leave the community, and the population declines. This sets off two additional feedback loops. The first of these population-related feedback loops operates via experiential learning. There are fewer community members sharing their experiences and so there is less transmission of knowledge within the community. This puts further downward pressure on payoffs, and induces more members to leave the community. Thus, this feedback loop is self-reinforcing.

In contrast, the second population-related feedback loop is self-dampening. A lower population can support a higher level of incentive-compatible sharing, and this effects moderates the otherwise negative impact on sharing that the initial loss of land induces.

The interplay of these two population-related feedback loops produces some interesting dynamics if the initial loss of land is not too large. In particular, within the threshold that characterizes Scenario 3, the population eventually stabilizes (at a permanently lower level), and once the population has stabilized, the stock of traditional knowledge starts to rise again and eventually stabilizes (at level lower than its initial stock). Sharing initially decreases but it too eventually rises again, and stabilizes at full sharing. Nonetheless, the stabilized community is smaller and less productive than the pre-disturbance state. Payoffs are significantly lower, and a large amount of traditional knowledge is lost. Figures 11 and 12 depict the impact on key variables under this scenario when the reduction in the land index is 64.1 percent ($q = 0.641$).

7.5 Scenario 4

Scenario 4 occurs when $q > q_{34}$. In this scenario, the land loss is so large that none of the variables stabilize over time. The aforementioned self-dampening population-related feedback loop is continually outweighed by the self-reinforcing feedback loops, and the population continually declines. The probability of harvest success continually falls, sharing amongst community members plummets, and knowledge continuously declines. The community completely collapses. The collapse occurs earlier in time for higher values of q. Figures 13 and 14 depict the impact on key variables under this scenario when the reduction in the land index is 66.6 percent ($q = 0.666$).

8. Limitations

The model and numerical simulations have a number of limitations. First, the decision by an individual to leave the community is not based on properly specified rational expectations of long run payoffs. To do so requires much more programming and access to computational power than was possible for this project. Whether requiring a full rational expectations equilibrium would change the results substantially is difficult to determine, but it seems reasonable that it would not. The feedback loops that determine the dynamics of the community would not be changed fundamentally, and any outflow of people from the community will generate those feedback loops. Nonetheless, a more complete model would incorporate a proper specification of future expectations and payoffs.

Second, the model assumes that harvest outcomes on the same traditional territories are independently distributed. This makes the model much simpler to solve but in practice there is likely to be some correlation across harvest outcomes, especially on small territories.

Third, the thresholds values of q presented in Section 7 are dependent on the assumed parameter values. Comparative statics are required to determine how the threshold values differ when the base parameter values change, and to ensure that the dynamics displayed by the model are not overly sensitive to these background parameter values.

9. Discussion and Policy Implications

The United Nations Declaration on the Rights of Indigenous Peoples Article 31 states that "Indigenous peoples have the right to maintain, control, protect and develop their cultural heritage, traditional knowledge and traditional cultural expressions." Furthermore, Article 26 states that "Indigenous peoples have the right to the lands, territories and resources which they have traditionally owned, occupied or otherwise used or acquired," and that "[s]tates shall give legal recognition and protection to these lands, territories and resources. Such recognition shall be conducted with due respect to the customs, traditions and land tenure systems of the Indigenous peoples concerned." (United Nations, 2008).

Indigenous peoples are asking for land sovereignty and cultural recognition as "the use of their TEK is necessary for cultural survival, and it is through their cultures that healthy ecosystems are maintained." (Mauro & Hardison, 2000). International policy processes have urged governments around the world, "to recognize and protect TEK for the conservation and sustainable use of biological diversity as well as to promote its wider application in resource management and biodiversity conservation" (Gómez-Baggethun et al., 2013).

In addressing these issues, policy makers must understand the relationship between traditional territories and traditional knowledge, and the key role that this relationship plays in Indigenous communities. My paper has looked at this relationship through an economic lens, and shown that conventional economic analysis can be brought to bear on these issues in a way that points to how incentives – which are potentially changed by public policy – play a key role in the determination of community structure and viability.

Traditional knowledge is also increasingly being integrated into environmental assessments, project planning, and resource management (CEAA, 2016). For example, in environmental assessments, it has been argued traditional knowledge should be a valued ecosystem component in the assessment process. A valued ecosystem component is an environmental element of an ecosystem that is identified as having scientific, social, cultural, economic, historical, archaeological or aesthetic importance" (CEAA, 2016). If traditional knowledge is to be treated as a central component of assessment, the type of research presented in this paper could be useful in guiding that assessment. In particular, it should be possible to construct an economic value of traditional knowledge using standard welfare measures (such as compensating variation) using the framework that underlies the model used here.

The Task Force on Aboriginal Languages and Culture (2005) outlined a strategy for the revitalization of First Nation, Inuit, and Métis languages and cultures. The report emphasizes that the "most important relationship embodied by First Nation, Inuit and Métis languages is with the land" (Task Force on Aboriginal Languages and Culture, 2005). The Task Force recommends that the connection between Aboriginal peoples and traditional lands be restored, as the land is integral for identity and culture. While my paper does not address the impact of *increase* in land quantity or quality, it could be modified and adapted to do so. Whether or not the feedback loops identified here can run in reverse, leading to cultural revitalization, is a question worth exploring further.

Extensions to this research could also examine network learning, and more complex community structures. In particular, network learning could be used to better model the transmission of traditional knowledge. More complex community structures, including elements of societal hierarchy and private ownership over some resources, could also be usefully examined.

Finally, the model developed here could be used to examine the potential effects of climate change on Indigenous communities. In particular, climate change is likely to add more uncertainty to the harvest process, and possibly reduce the productivity of traditional knowledge when the land base has been rapidly altered by that change. On the other hand, the ongoing experiential learning that underlies traditional knowledge could provide a mechanism through which communities can successfully adapt to change. A case study on the Inuit peoples of Arctic Bay, Nunavut, examined community vulnerabilities due to climate change (Ford et al., 2006), and the following excerpt from that study speaks to these two aspects of the role for traditional knowledge in the face of a changing northern climate:

> *"The traditional knowledge used to make predictions, however, has become less dependable as the result of changing climatic conditions and has made hunting more hazardous…The sharing of knowledge facilitates the communication of information about risks and adaptive strategies. Those*

knowledgeable and experienced on the land act as an 'institutional memory', maintaining and transmitting local knowledge and providing information during periods of change." (Ford et al., 2006)

If traditional knowledge can help Indigenous communities adapt to climate change then it could become increasingly vital for those communities, and its loss over time ever more costly.

10. Conclusion

In Indigenous communities across Canada and beyond, the loss of traditional knowledge is a real and pressing concern. This paper has presented a model which examines this issue using a conventional economic lens, focusing on risk-pooling, moral hazard and incentives. The numerical simulations show how a one-time loss of land base and its impact on traditional knowledge can negatively affect communities over long periods of time, and with potentially complex dynamics. In the most drastic case, a one-time loss of land can result in the complete collapse of the community.

If policies aimed at preserving and revitalizing Indigenous communities are to be successful, then those policies must be developed using a framework that acknowledges the key role of traditional knowledge and its link to the land. My paper has shown that traditional economic analysis can potentially play a valuable role in developing such a framework.

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Appendix: The Optimal Restoration of Incentive-compatibility

Figure 5 illustrates a set of incentive-compatibility thresholds drawn for different values of p. The blue incentive-compatibility threshold (furthest to the left) corresponds to the lowest value of p; the green incentive-compatibility threshold corresponds to the highest value of p. Associated with every level of p is a corresponding critical value of s below which all values of of s and n are incentive-compatible. These levels of s, denoted as $\bar{s}(p)$, are the vertical lines in Figure 5 associated with the incentive-compatibility thresholds for each level of p. As p increases and the threshold shifts to the right, the value of $\bar{s}(p)$ increases at a decreasing rate. If $\bar{s}(p)$ is large, then there is a greater range of s where any value of n will be incentive-compatible. If the sharing regime has $s < \bar{s}(p)$ then a community of any size will be incentive-compatible.

Given values for p and other parameters, we can solve for $\bar{s}(p)$ by taking the limit of the incentive-compatible threshold as n goes to infinity:

$$\bar{s}(p) = \frac{e^{\frac{\ln\left(-\frac{\omega p+1}{e^{-\frac{\psi}{p}}p - e^{-\frac{\psi}{p}} - p}\right)p - \psi}{p}} - 1}{p\omega} \tag{32}$$

$\bar{s}(p)$ reaches its maximum value when $p = 1$, where it takes the value:

$$\bar{s}_{max} = \frac{e^{\ln(\omega+1)-\psi} - 1}{\omega} \tag{33}$$

Now consider the problem of the social planner. As all community members are homogeneous, one can look at a single individual as a representative of the entire community. The planning problem is to maximize the expected utility of a representative member subject to the incentive-compatibility constraint:

$$\max V1\; s.t.\; V1 - V0 = 0 \tag{34}$$

where $V1$ is the expected payoff from exerting effort, and $V0$ is the expected payoff of not exerting effort, when all other agents exert effort. Solving this problem for s yields an expression identical to that for $\bar{s}$; the maximized payoff for the community member occurs at $\bar{s}$. Recall that at $\bar{s}$ any community size is incentive-compatible. Thus, in order to maximize the expected payoff for community members, n should be set as large as possible, and s should be set to ensure incentive-compatibility.

Figures

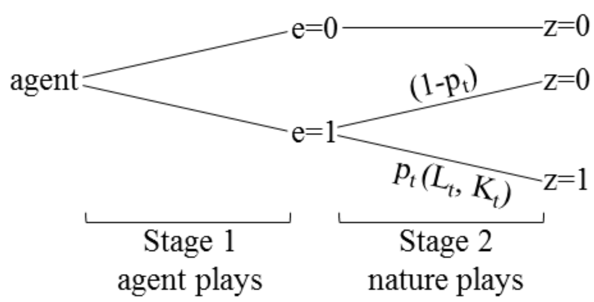

Figure 1 *Stochastic production process game tree*

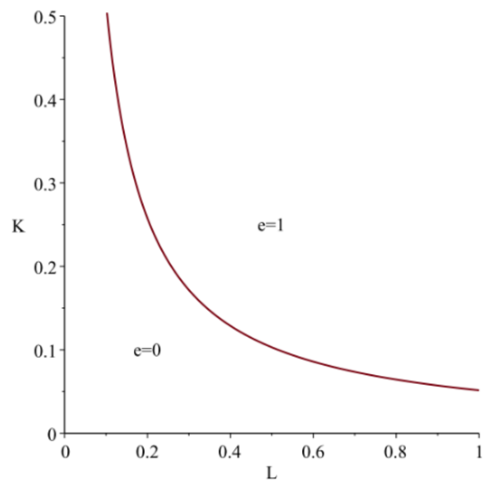

Figure 2 $\overline{K}$ *in* (L, K) *space*

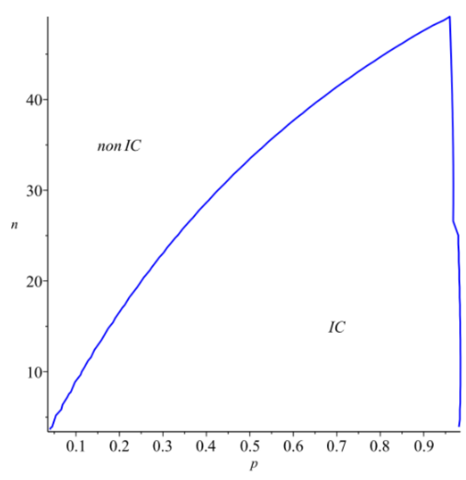

Figure 3 *Incentive-compatibility threshold in* (p, n) *space*

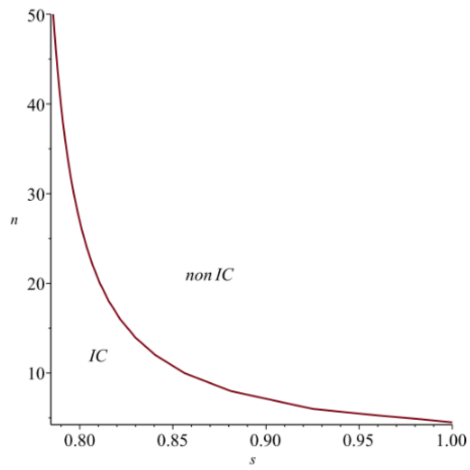

Figure 4 *Incentive-compatibility threshold in* (s, n) *space when* $p = 0.05$

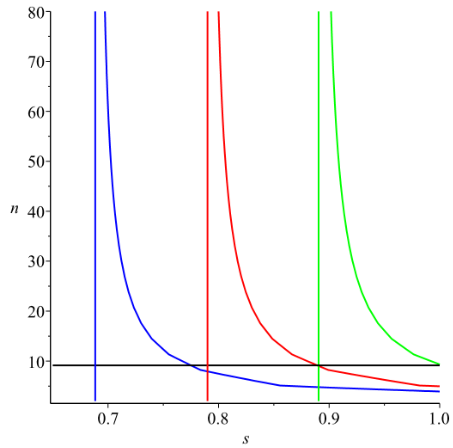

Figure 5 *Incentive-compatibility threshold in* (s, n) *space when* $p = 0.3, 0.5, 0.9$

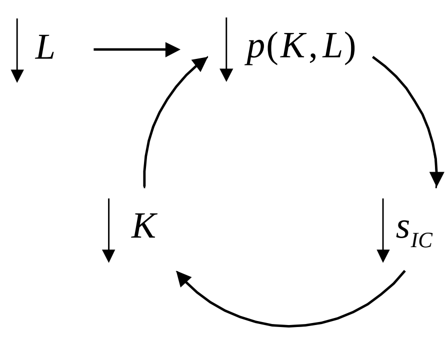

Figure 6 *Exogenous reduction in L feedback loop*

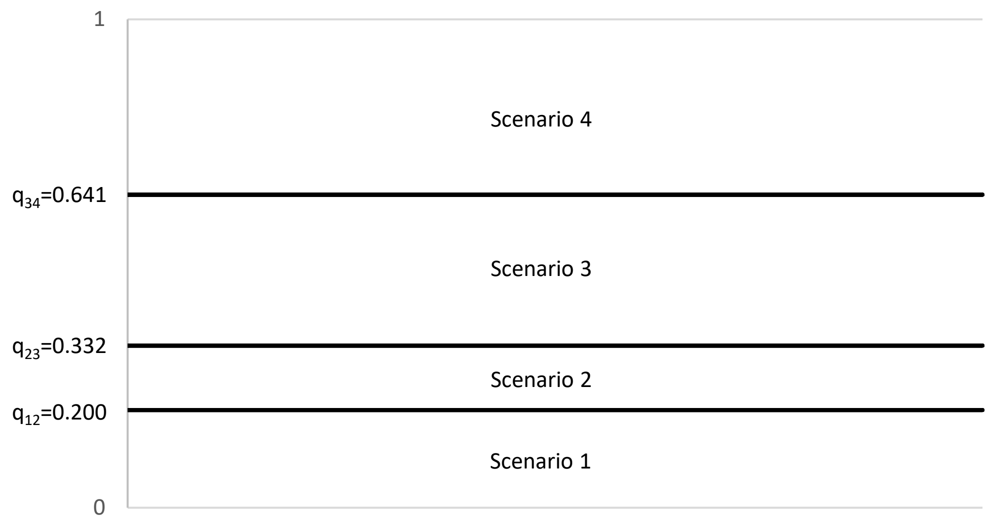

Figure 7 *Threshold values of q and associated scenarios*

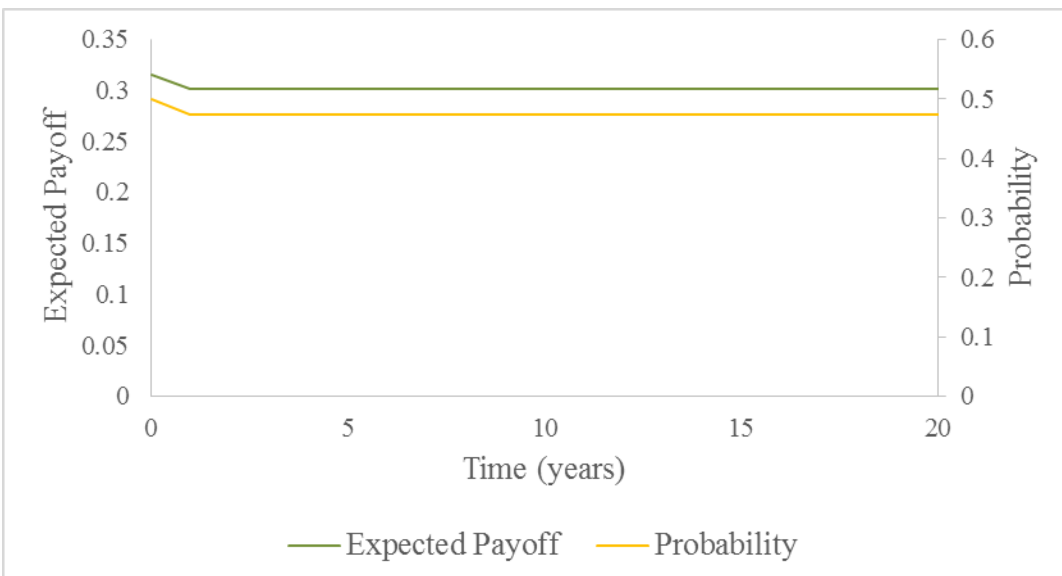

Figure 8 *Change in p and v when $q = 0.100$*

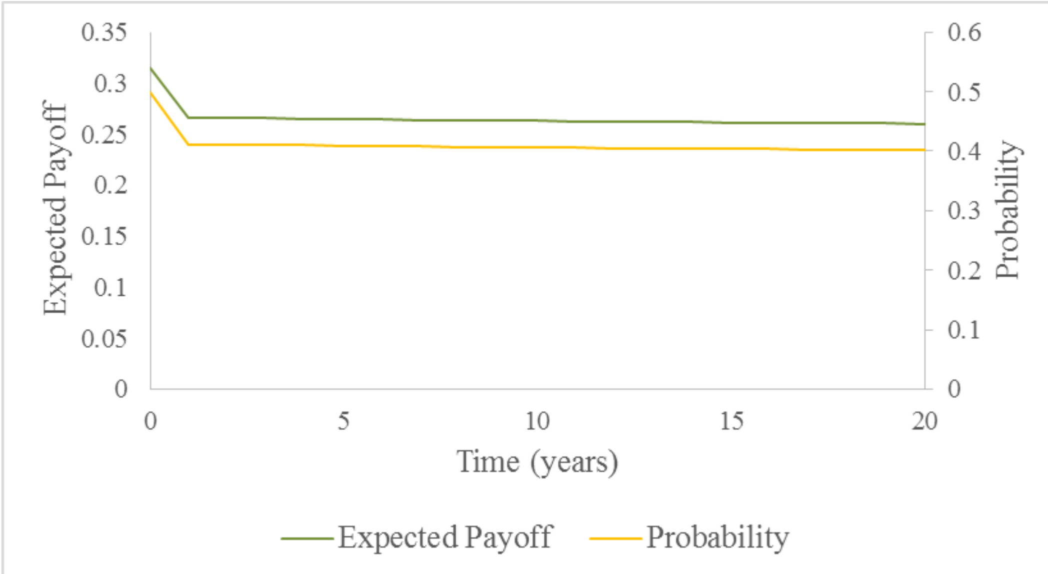

Figure 9 *Change in p and v when* $q = 0.300$

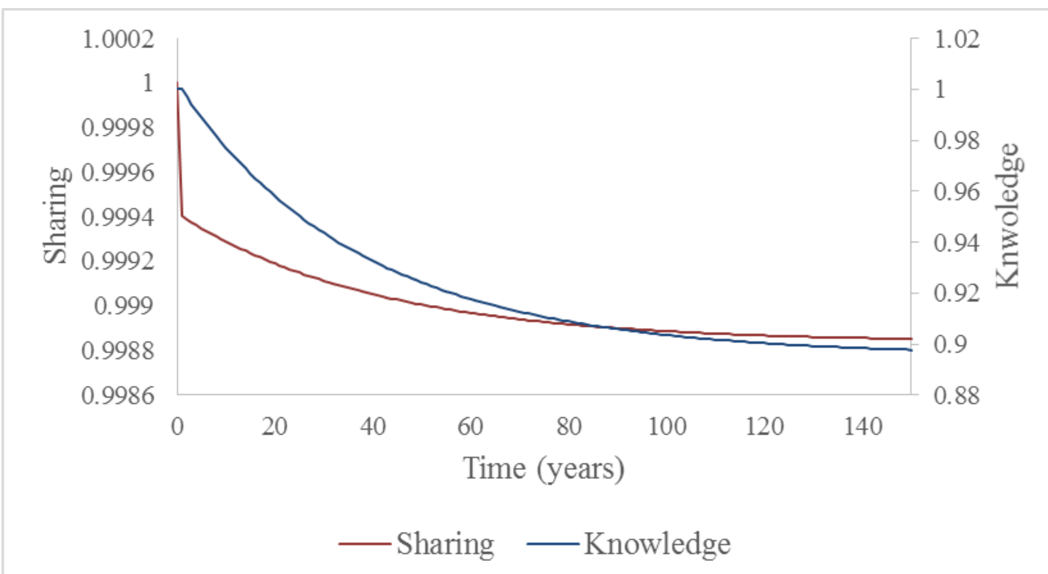

Figure 10 *Change in K and s when* $q = 0.300$

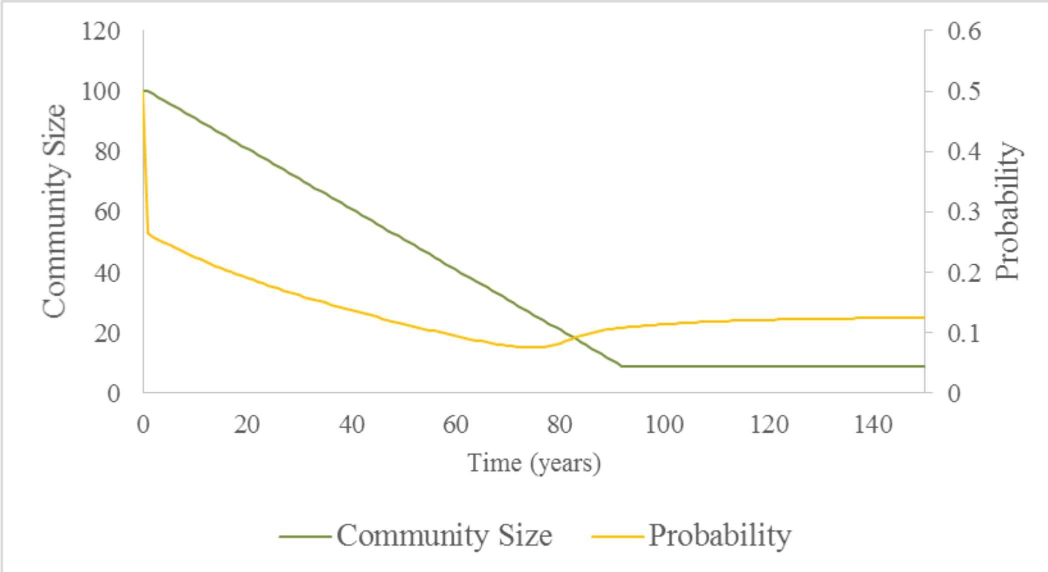

Figure 11 *Change in* n *and* p *when* $q = 0.641$

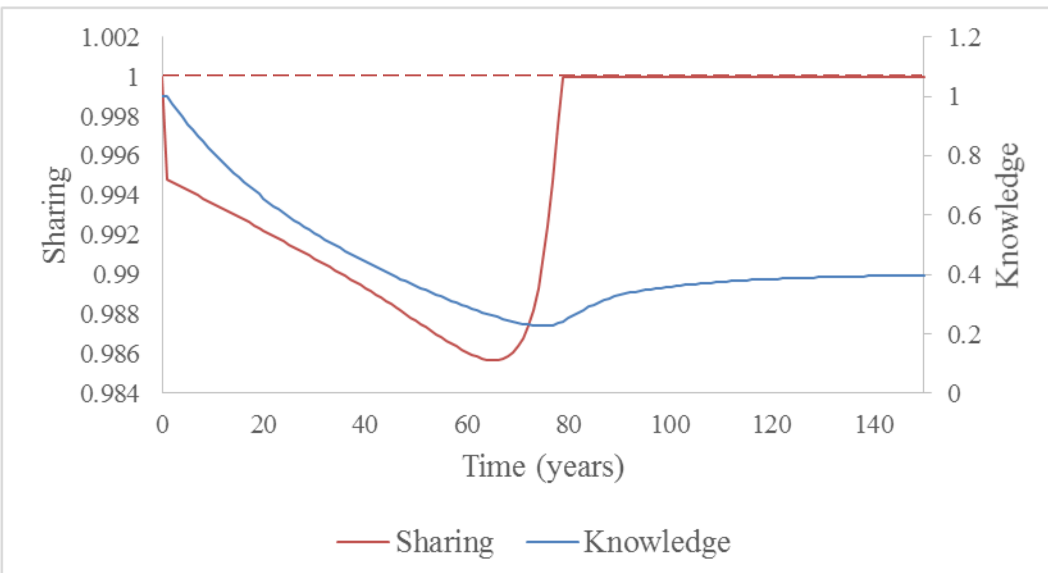

Figure 12 *Change in* s *and* K *when* $q = 0.641$

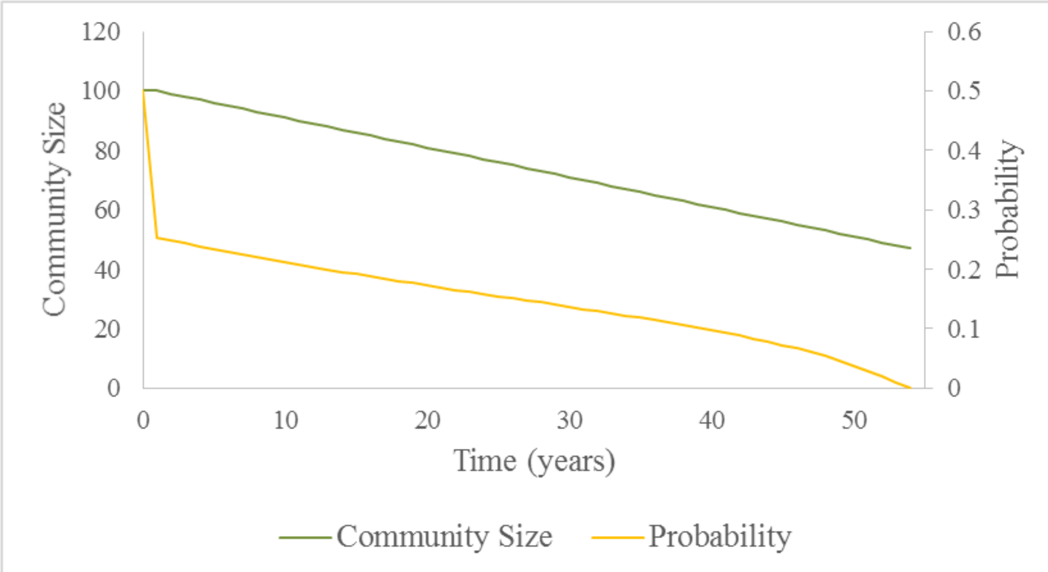

Figure 13 *Change in* n *and* p *when* $q = 0.666$

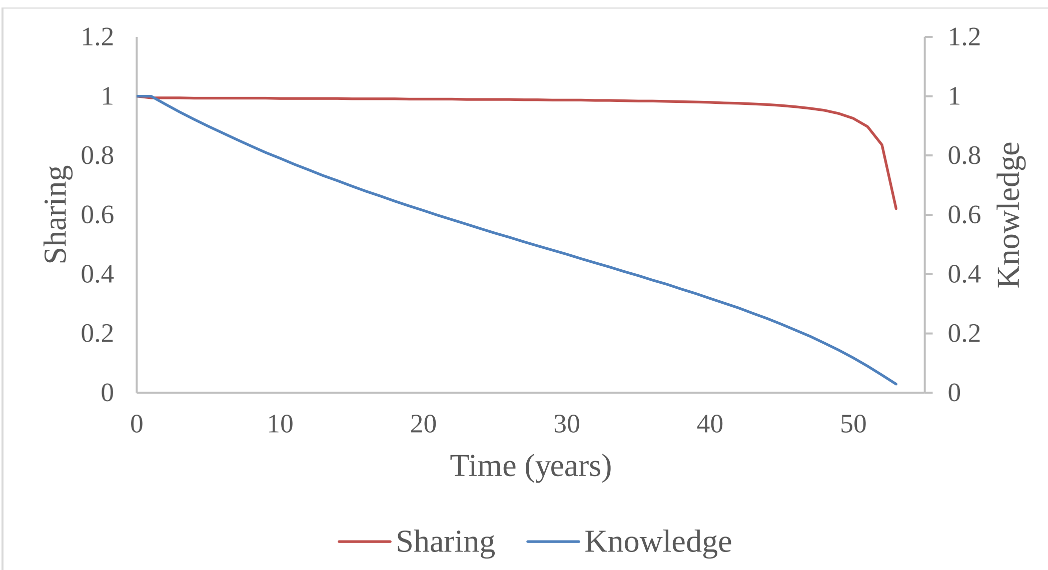

Figure 14 *Change in* s *and* K *when* $q = 0.666$

Tables

n_0	100
K_0	1
L_0	1
s_0	1
E_0	1
v_0	$v1$
w_0	φv_0

Table 1 *Initial conditions in a stable full sharing community*

α	0.95
β	0.95
γ	5.0
δ	0.02
η	0.5
θ	1.0
φ	0.75
ψ	0.0025
ω	0.75

Table 2 *Base case parameter values*