MITIGATION OF AQUATIC CONTAMINANT HAZARDS – ECONOMIC ANALYSIS OF REGIONAL COSTS AND BENEFITS

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ABSTRACT

Water contamination is a potential health risk with considerable societal costs. Thus, measures that mitigate the risk are generally considered justified. This paper assesses the costs and benefits of such mitigation actions from economic point of view. We use as a case study the artificial recharge system in Kokemäenjoki River in Finland that supplies household water to 300 000 inhabitant Turku region. Realization of water contamination risk is likely to have consequences on the regional economy. Large scale water contamination would adversely affect the health of the population in the receiving region. Our approach is to partition the problem in two phases: 1) prevention of risk – the decision for the level of mitigation measures and 2) actualization of risk – adjustment during the hazard (or lack of it) and subsequent recovery. The first phase represents the cost side of the analysis – the foregone consumption that is needed for the productivity enhancing mitigation investment. The second phase is for measuring the benefits – what is the benefit of an investment, the avoided disruption in economic activity. The major pathways of economic consequences are carried through reduced labor productivity in the region due to increased amount of sick leaves and through increased demand for the health care services. These direct economic effects induce higher order effects that affect regional and industrial economic equilibria. Further complication is the dynamic nature of the problem. Therefore, a dynamic regional general equilibrium assessment seems suitable tool for analysis. We use dynamic regional AGE model VERM as the main tool of our study. In the model we apply monthly time periods in order to model the short duration hazard accurately. We also apply excess capacity of capital to account for restricted adjustment possibilities at the very short run.

1. Introduction

Freshwater ecosystems provide numerous services such as drinking water, irrigation, fishing and recreation. Water contamination is a potential health risk with considerable societal costs. Thus, measures that mitigate the risk are generally considered justified. Water safety is based on protection of the source water. Water contamination causes adverse effects especially in developing, but also in developed countries each year. In addition to traditional contamination by microbes and other biological substances, modern technologies have produced an array of harmful chemical substances that spread in water system and typically have very high persistence. In this paper we consider a general framework for assessing the costs and benefits of a water contamination hazard. For the sake of concreteness, we investigate the possible hazards in the functioning of artificial recharge system in Kokemäenjoki River. This is very suitable exemplary case for our purposes as it is large scale investment for Finnish water security that just recently went into operation. The potential hazards of the investment have not thus far been systematically assessed. Our study utilizes the results of biological and chemical water quality assessments, modeling of their distribution by physical water system models and finally the results of health effects based on water contaminant flows.

Finnish consumers perceive their potable water pure and direct consumption of tap water is common practice. Therefore, the effects of water contamination might spread to geographically wide areas in relatively short time. Adverse health effects have consequences to local labor force and economic activity. In order to measure justifiable level of mitigation spending, systematic cost-benefit analysis is needed. The costs of the mitigation are the investments needed to mitigate the risk. We assume that a mitigation action is an investment that does not yield any direct utility to consumers but decreases the risk of reduced productivity and utility derived from leisure. In the absence of a risk, the resources directed to such investments could be put in other, more productive uses. However, the benefits of such investments are much more difficult to measure due to many uncertainties and subjective valuations. The benefits include the aforementioned avoided negative effects on productivity and leisure quality and utility derived from subjective tendencies to avert risk and uncertainty[1].

When a hazard occurs, the economic system's normal mode of operation becomes disrupted. It is useful to distinguish the supply and demand side effects of an epidemic. On the supply side there is decreased labor productivity and on the demand side increased demand for health care services and decreased demand for leisure activities. In case of water contamination, the hazard induces change in total output as labor productivity temporarily decreases. Therefore, market disruptions ensue as firms might not be able to deliver their commodities the way they do in normal situation. Depending on the level of inventories and epidemic duration, this shortage might not even come to realization. However, the information about the magnitude of effects, its coverage and duration are very likely to be imperfect. Because of sudden disruption to economic activity, it is possible that during this phase the economy might dramatically deviate from traditionally conceived equilibrium state. Thus, economically rational behavior is hardly the

[1] Sometimes it is useful to distinguish risk and uncertainty in parallel to Knight (1921) where risk is something readily measurable by probabilistic means whereas uncertainty has no meaningful probabilistic interpretation. Risk-averse behavior is empirically established: from the choices with the same expected returns, the one with lower risk is chosen. Moreover, uncertainty-averse behavior is empirically established as well. This means that of the choices with the same probabilistic risk, the one with less ambiguity is chosen. Therefore there is likely to be over-mitigation of risks of any probabilistically measurable exogenous events that is consistent with perceived utility, and even more so for events with more ambiguous uncertainties.

norm during the realization of a hazard and decision-making is likely to be more myopic than in normal situation. Due to disruptions of market mechanisms, central planning and coordination might well be better justified than during normal economic situation.

The recovery[2] takes place after the disaster. The economy will adjust to changes in its resource base with available technologies. Although the disaster certainly causes harm, there might also exist an opportunity to gain from "creative destruction" and adopt newer, more productive technologies. Such "creative destruction" is the inherent factor of dynamic economic change. Empirical evidence supports the idea of increased GDP growth after natural disaster (Albala-Bertrand, 1993) but there are reasons why "creative destruction" might not take place in every, or even most of the disasters. If the duration is not long enough to carry out full new investment and the companies find that getting back to previous output level as soon as possible is more sensible strategy, the opportunities of new technology adaptation are likely to be foregone (Hallegatte & Przyluski, 2010). Hallegatte and Dumas (2009) found that although "creative destruction" would take place, it could never be large enough to counter the overall negative effects. Furthermore they speculate that the empirical evidence supporting "creative destruction" has not adequately distinguished it from other effects like catching-up and reconstruction-led Keynesian boom (2009, p. 777). Thus, the hopes for "creative destruction" in context of a sudden, disruptive hazard should not be too high.

Hazards, natural and man-made, have economic consequences that are not easy to measure. Evidently, the disruptions to economic activity in the sectors directly affected are the most proximal and visible consequences of such events. In reality, the effects do not end there but will accumulate as the affected sectors' difficulties will be felt on sectors most closely attached to them, and eventually through general equilibrium effects, on the whole economy. For hazards like water contamination that have spatially restricted consequences, local effects are likely to affect the neighboring regions' economies as well. According to spatial equilibrium theory, the consequences depend on regional composition of tradable and non-tradable sectors. If the affected region is dominated by non-tradable sectors, it is likely to forego the faster recovery benefits of trade but also to be less prone to lose some markets to its neighboring regions. On the one hand the trade among regions makes the recovery processes more flexible, but on the other hand it might permanently decrease the competitiveness of the affected region in comparison to its neighbors. The effects to the rest of the country depend on whether a region is net importer or exporter. The loss in net exporter's output is felt negatively in other, importing regions whereas net importer's loss increases demand for the rest of the economy. Recovery process with new investments is likely to cause demand surge in the affected region, which is economic burden for that particular region as its consumption possibilities temporarily decrease. However, that surge will decrease the sum total economic costs of the disaster as other regions' incomes increase.

Pragmatic value of our analysis would significantly gain from identification of the regional economy's bottlenecks that could aggravate the losses. In our epidemic case there is one particular bottleneck that readily suggests itself: the productivity of health care personnel. During an outbreak there is likely to be increased demand of health care services coinciding the productivity decrease. Successful functioning of health care services is likely to reduce the

[2] For disasters with considerable capital damages, recovery as short run and reconstruction as long run phenomenon can be distinguished. Recovery in this context means the phase when the economy returns to normal mode of operation with current, damaged resource base and reconstruction is the phase during which the resource base returns to its steady state level.

epidemic duration. If the personnel in health care services are not adequately protected against hazards by e.g. additional precautionary vaccination, it is as likely as the rest of the population to experience the detrimental health effects and ensuing decreased productivity. Decreased productivity of health care service personnel might thus further prolong the epidemic duration. Indeed, there is likely to be higher social marginal utility associated to protection of health care personnel from the hazards than rest of the population.

Our analysis relies on economics of natural hazards and health economics applications for epidemics. Both are fields of study in applied economics that have gradually increased their relevance in guiding public decision making. Information about the mitigation decisions to natural hazards and global epidemics is becoming more valuable due to population growth, increased mobility of people, climate change and related factors. We apply economic modeling techniques to carry out the analysis. Modeling is required tool for consistent assessment of complex interlinked phenomena. Although many types of economic models have been used for this kind of analysis, the applied general equilibrium (AGE) modeling seems to be the most suitable tool available. However, its shortcomings need to be duly recognized and addressed. Fortunately, few helpful modifications have been recently developed for AGE models that improve the analysis of sudden disruptions. We also need to assess the possible policy options for both mitigation and aftermath.

This paper is organized as follows. Chapter 2 reviews the relevant literature and theory of natural hazard and health economics. It describes the relevant theoretical considerations that aid modeling work. Chapter 3 introduces the material and methods; the model we use in our analysis, the problem specific tweaks in it, and the model inputs we gathered in order to analyze our contamination scenarios. Chapter 4 collects the results, chapter 5 discusses their relevance and chapter 6 concludes the paper.

2. Economics of natural hazards and epidemics

Theoretical underpinnings of our work can be traced back to health economics, economics of natural hazards, endogenous growth theories and optimization over time. Health economics is vast area of study that contains more than management of sudden epidemics. Economics of natural hazards on the other hand explicitly deals with sudden, unexpected disruptions. The mitigation investment can be seen as kind of an investment to productivity improvement which interprets as endogenous growth. Optimization over time applies to investment decisions in general. We start theoretical review from economics of natural hazards as it sheds light on what we should consider when we fine-tune our AGE model for the epidemic case.

The economic theory of disasters is relatively young, commencing with Dacy and Kunreuther's (1969) seminal book *"The Economics of Natural Disasters"*. The book was written in aftermath of 1964 Alaska earthquake and as a reaction to National Flood Insurance Act of the United States in 1968. It proposes improvements in disaster insurance system that would be alternative to "*current paternalistic Federal policy*" (1969, p. ix). They suggest that short-term recovery analysis should be dealt in microeconomics domain and the longer term effects in growth theory. For the short-term recovery Dacy and Kunreuther suggest deviating from perfect information assumption in order to deal with uncertainty immediately after disaster. Therefore, public sector resource allocation in order to decrease informational uncertainties concerning hazards could be justified by economic reasoning. Microeconomic supply and demand analysis should be done carefully as supply and demand curves may shift unexpectedly after the disaster. Basic scenario in general equilibrium analysis requires that if supply contracts while demand stays constant, the prices should rise. Empirical findings of natural hazards that decrease the supply of some commodities do not confirm this economic reasoning as prices are generally not affected. Dacy and Kunreuther address this to sympathetic feelings towards the hazard victims. It is still open to debate whether the situation holds only for large scale natural disasters and if so, what would be the level of publicity of difficulties experiences by the hazard victims that would trigger those sympathetic feelings to rule over the economic rationales.[3] For the long term recovery, Dacy and Kunreuther note that the general growth model that ignores variation in capital stock (i.e. vintages) displays the recovery process too pessimistically as it does not allow for 'creative destruction' that would enhance the quality of post-disaster capital stock; as destroyed capital stock is replaced in recovery process it is likely to be of newer, more productive technology. For our problem this proposition shows more problematic as the factor of production that is affected is labor and human capital. Therefore, we do not see much room for creative destruction in context of epidemics and can expect permanent reduction of human capital when compared to baseline development without epidemic effects. On the other hand if the epidemic is prolonged, some shift to more capital intensive technology might happen and therefore increase the amount of new technology in the economy. And, as we will see later on, the capital use might actually contract which would effectively delay the shift to newer technologies.

Economic realities and economics itself as discipline have evolved since Dacy and Kunreuther wrote their book. Okuyama (2003) reviewed and updated their framework to allow for more recent developments in economic theory. First, the concept of uncertainty was vaguely defined by Dacy and Kunreuther and corresponds more to risk if we are to follow the classic distinction between risk and uncertainty proposed by Knight in (1921). Therefore, their analysis is helpful for promote pre-disaster preparedness with known probabilities but not so well suited to analyze uncertainty that affects production decisions after the disaster. Second, Okuyama extends the long-term recovery considerations to include regional effects and developing countries' situations as well. He also investigates the growth model with saving and investment dynamics affecting the recovery of capital stock. After the disaster, demand for reconstruction causes savings rate to increase. That causes resources to accumulate to recovery investments and thus recovery speeds up. As savings rate increases, the consumption will contract. Okuyama extends this case to account for technological improvements due to new more advanced capital installed in recovery process which have similar but somewhat stronger effects. Recovery rate is influenced by the mixture of old and new capital in the economy. For our case the same capital accumulation process is still relevant, but only as subject to temporary decrease in labor productivity. As productivity decreases, the shift to new capital is likely to be delayed and we have the case of inverse creative destruction – prolonged use of obsolete technology. Next, let us look more formally at the dynamic effects of temporary change in labor productivity caused by an epidemic.

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[3] Social institutions are most likely the underlying factors as benefiting of victims' difficulties is not deemed to be appropriate. In this sense raising the prices during a hazard would harm the reputation of a firm that does so. Conversely, not taking advantage of the situation as an act of goodwill might be economically rational in the long run. Thus, the equilibrium formation is affected by reciprocal altruism.

Optimal level of mitigation measures

When an economy decides to invest in epidemic mitigation measures, it necessarily forgoes part of its consumption as that investment does not yield direct utility. On the other hand if the investment enhances economy's production capabilities in the future by securing more stable productivity growth, it might increase the output and therefore after savings consumption level as well. Investment is feasible in economic sense if the gains cover the expenses. The expense of the investment is the utility from consumption that is foregone. There are two types of gains in our case: 1) direct increase in welfare due to more (and perhaps better quality) leisure and 2) indirect increase in utility due to increased consumption possibilities due to higher productivity. In order to more consistently study optimal mitigation level, we resort to mathematical formulation commonly used to describe economic optimization process.

It should be noted that both the direct and indirect gains of the investment involve labor-leisure decision: an epidemic decreases quality and amount of leisure (direct effect) and the productivity improvement due to mitigation enhances opportunities for leisure (indirect effect). In order to keep our presentation tractable, we abstract from labor-leisure decision in our mathematical description of the problem.[4] We start from Ramsey growth model that defines economy as consisting of representative agents maximizing their utility over time.[5] By this model we can examine the dynamics of the economy and its balanced growth path.

Our problem closely resembles endogenous growth model of learning-by-doing type suggested first by Arrow (1962) and later on fully developed by Romer in (1986) and (1990). The model assumes that productivity of capital increases when workers gradually learn better and more efficient ways to use it. Therefore productivity can be presented as a function of capital stock. In our case we modify this model by concentrating to a particular investment that has productivity increasing effect: investment to water contamination mitigation that increases labor productivity when compared to non-mitigation case. Our presentation of the dynamics closely follows Greiner (2003) deviating only by incorporating decreasing marginal productivity gains. Accumulation process of knowledge capital is adopted from Hallegatte and Dumas (2009).

Let us denote the mitigation investment at time t as I_t^M. The mitigation capital stock at time t is $M(t) = \int_{-\infty}^{t} e^{\delta^M (s-t)} I_s^M ds$ where δ^M is the depreciation rate of mitigation capital.[6] In the basic learning-by-doing model it is assumed that human capital does not erode but as in our case the productivity is improved by physical capital, we should assume positive, non-zero depreciation rate. Productivity is a function of the mitigation capital. More specifically we assume that the weighted productivity of current capital stock is defined as

(1) $$\Lambda(t) = \frac{A_t I_t^{\varphi} + \int_{-\infty}^{t-1} e^{\delta^M (s-t+1)} \Lambda_s I_s ds}{M_t} = \frac{A_t I_t^{\varphi} + \Lambda_{t-1} M_{t-1}}{M_t} = \frac{A_t I_t^{\varphi}}{M_t} + \Lambda_{t-1} \frac{\dot{k}}{k}^{-1} = \frac{A_t I_t^{\varphi}}{M_t} + \Lambda_{t-1} \frac{k}{I - \delta k}$$

[4] Part of the labor-leisure decision could be included in our simulation exercise by associating the epidemic duration with a decreased demand for leisure activities.

[5] Although our problem is stochastic by nature, a deterministic presentation of the problem is more illustrative and conveys the fundamental message. Good description of a stochastic Ramsey growth model is (Merton, 1975).

[6] In multi-sector model that we are going to apply, it is realistic and empirically defendable decision to allow different depreciation rates for general and mitigation capital.

Here $\Lambda(t)$ denotes the weighted productivity of capital stock at use at time t and A_t[7] is the productivity of newly installed capital at time t. We assume decreasing marginal productivity gain for the investment. Parameter φ determines how much productivity improvement the mitigation capital stock generates. We assume that $\varphi > 0$ so that the investment actually improves productivity.[8] The time derivative for productivity improvement is

(2) $$\dot{\Lambda} = \frac{I^{\varphi}}{M}(A - \delta^M \Lambda) .$$

For convenience, we assume general, exogenous productivity growth and population growth to be zero.

With our model we can compare competitively and socially optimal mitigation investment levels and we will see that social optimum is higher and yield higher lifetime utility as well. This result arises naturally as the private firms cannot incorporate the social optimum in their decision making and therefore they underinvest in mitigation capital. Let us first examine the competitive case. The aggregate production function of the economy is $Y_t = F(K_t, \Lambda(t)L_t)$, where the output is function of capital K_t, labor L_t and labor enhancing productivity $\Lambda(t)$. By dividing with labor, we get the familiar per capita form $y_t = f\big(k_t, \Lambda(t)\big)$. Representative household maximizes its lifetime utility u by choosing the level of consumption:

(3) $$\max_{\{c(t)\}} \int_0^{\infty} e^{-\rho t} u\big(c(t)\big)dt$$

subject to its budget constraint $\dot{k} = f\big(k_t, \Lambda(t)\big) - c - \delta k$. For concreteness and simplicity we apply here Cobb-Douglas production function $y_t = \Lambda^{\alpha} k^{1-\alpha}$ which yields budget constraint

(4) $$\dot{k} = \Lambda^{\alpha} k^{1-\alpha} - c - \delta k.$$

where α is the labor factor share. In order to model competitive economy we need to assume that the endogenous productivity improvement does not enter the representative agent's maximization problem. Thus the current-value Hamiltonian for this case is simply

(5) $$H = u(c) + \lambda(\Lambda^{\alpha} k^{1-\alpha} - c - \delta k).$$

The first order conditions for the competitive case are

(6) $$u'(c) = \lambda \qquad \text{(FOC C1)}$$

(7) $$\dot{\lambda} = (\rho + \delta)\lambda - \lambda(1-\alpha)\Lambda^{\alpha} k^{-\alpha} \qquad \text{(FOC C2)}$$

For the social optimum we assume that the productivity improvement actually enters the maximization problem and thus we have an extra condition for productivity improvement constraint

(8) $$\dot{\Lambda} = \frac{(\Lambda^{\alpha} k^{1-\alpha} - c)^{\varphi}}{M}(A - \delta^M \Lambda).$$

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[7] Productivity increase A can be defined as $A = Y^M/Y$, where Y^M is the output with mitigation and Y without it. It applies that $Y^M > Y$ when $L^M = L$.

[8] This is therefore a case where an investment has positive externalities. A case of $\varphi < 0$, negative externalities is possible as well if we could think of a new technology that would actually increase the water contamination risk.

This constraint effectively sets the limit to how much the social planner could actually improve productivity by mitigation investment. The resulting Hamiltonian is

(9) $$H = u(c) + \lambda_1(\Lambda^{\alpha}k^{1-\alpha} - c - \delta k) + \lambda_2\left(\frac{(\Lambda^{\alpha}k^{1-\alpha} - c)^{\varphi}}{M}(A - \delta^M\Lambda)\right)$$

and the first order conditions are

(10) $$u'(c) = \lambda_1 + \lambda_2(A - \delta^M\Lambda)\frac{\varphi I^{\varphi-1}}{M}$$ (FOC S1)

(11) $$\dot{\lambda}_1 = (\rho + \delta)\lambda_1 - \lambda_1(1-\alpha)\Lambda^{\alpha}k^{-\alpha} - \lambda_2 A(1-\alpha)k^{-\alpha}\frac{\varphi I^{\varphi-1}}{M}$$ (FOC S2)

(12) $$\dot{\lambda}_2 = \left(\rho + \frac{\delta^M I^{\varphi}}{M}\right)\lambda_2 - \lambda_1\alpha\Lambda^{\alpha-1}k^{1-\alpha} - \lambda_2 A\alpha\Lambda^{\alpha-1}k^{-\alpha}(1 - \Lambda\delta^M)\frac{\varphi I^{\varphi-1}}{M}$$ (FOC S3)

Parameters λ, $\lambda_1$and λ_2 are the shadow prices for the constraints. In the competitive and social problem, the shadow prices for capital accumulation, λ and λ_1 , are equal in both of the cases. In the social planner's problem there is also a shadow price for productivity improvement, λ_2. We can interpret FOC C1 and FOC S1 as measures for marginal utility and we see that it is higher in the social optimum when $\lambda_2(A - \delta^M\Lambda)\frac{\varphi I^{\varphi-1}}{M} > 0$. This is true when $A - \delta^M\Lambda > 0$, when the society invests more to its mitigation capital than it naturally erodes. In the equilibrium, the investment is equal to its marginal utility. Thus, in the social optimum the level of investment is higher as it is paid extra weighted shadow price for the productivity improvement that is equal to $\lambda_2(A - \delta^M\Lambda)\frac{\varphi I^{\varphi-1}}{M}$.

On the balanced growth path the consumption, capital and productivity all grow at the same constant rate and thus we have that $\frac{\dot{c}}{c} = \frac{\dot{k}}{k} = \frac{\dot{A}}{A} = g$. In the competitive case the time derivatives are

(13) $$\dot{c} = \Lambda^{\alpha}k^{-\alpha}c\left(\frac{1-\alpha}{\sigma}\right) - c\left(\frac{\rho+\delta}{\sigma}\right)$$

(14) $$\dot{k} = \Lambda^{\alpha}k^{1-\alpha} - c - \delta k$$

(15) $$\dot{\Lambda} = \frac{(\Lambda^{\alpha}k^{1-\alpha} - c)^{\varphi}}{M}(A - \delta^M\Lambda)$$

where σ is the inter-temporal elasticity of substitution. The growth rates are thus

(16) $$\frac{\dot{c}}{c} = \Lambda^{\alpha}k^{-\alpha}\left(\frac{1-\alpha}{\sigma}\right) - \left(\frac{\rho+\delta}{\sigma}\right)$$

(17) $$\frac{\dot{k}}{k} = \Lambda^{\alpha}k^{-\alpha} - ck^{-1} - \delta$$

(18) $$\frac{\dot{\Lambda}}{\Lambda} = \frac{I^{\varphi}}{\Lambda M}(A - \delta^M\Lambda).$$

Let us now denote the effective capital $\boldsymbol{k} = \frac{k}{A}$ and effective consumption $\boldsymbol{c} = \frac{c}{A}$. By differentiating these with respect to time we have the following dynamic system:

(19) $$\frac{\dot{\boldsymbol{k}}}{\boldsymbol{k}} = \frac{\dot{k}}{k} - \frac{\dot{A}}{A} = \Lambda^{\alpha}k^{-\alpha} - ck^{-1} - \delta - \left(\frac{I^{\varphi}}{\Lambda M}(A - \delta^M\Lambda)\right)$$ (DS C1)

(20) $$\frac{\dot{\boldsymbol{c}}}{\boldsymbol{c}} = \frac{\dot{c}}{c} - \frac{\dot{A}}{A} = \Lambda^{\alpha}k^{-\alpha}\left(\frac{1-\alpha}{\sigma}\right) - \left(\frac{\rho+\delta}{\sigma}\right) - \left(\frac{I^{\varphi}}{\Lambda M}(A - \delta^M\Lambda)\right)$$ (DS C2)

For the social optimum we differentiate FOC S1 with respect to time and have that $\frac{\dot{c}}{c} = -\frac{1}{\sigma}\left(\frac{\dot{\lambda}_1+\varphi\dot{\lambda}_2}{\lambda_1+\varphi\lambda_2}\right)$. Thus we can express DS S2 as

$$\frac{\dot{\boldsymbol{c}}}{\boldsymbol{c}} = -\frac{1}{\sigma}\left(\frac{\dot{\lambda}_1+\varphi\dot{\lambda}_2}{\lambda_1+\varphi\lambda_2}\right) + \left(\frac{I^{\varphi}}{\Lambda M}(A - \delta^M \Lambda)\right) \quad (21) \quad \text{(DS S2)}$$

DS S1 is equal to DS C1. The rest point of system DS C1 – DS C2 corresponds to balanced growth path of system (16) – (18). Therefore we can investigate the properties of balanced growth path by setting $\frac{\dot{\boldsymbol{k}}}{\boldsymbol{k}} = \frac{\dot{\boldsymbol{c}}}{\boldsymbol{c}} = 0$. Unfortunately this system does not have tractable solution and for more complete analysis we need to resort to simulation techniques.

Decisions during the hazard

An epidemic causes effective labor to decrease to a lower level and stay there for the duration of the epidemic. In the absence of perfect information, the firms can adopt a strategy between two extreme cases in such a situation:

1. Adjust the capital use as much as rate of return to investments allows.
2. Do not adjust the capital use and produce with current capital and labor mix.

Firm's choice of strategy largely depends on the uncertainty it runs into concerning the duration of the epidemic and the return to its investment to new capital. Longer the perceived duration, the more likely the firm is to obtain the first strategy. The latter strategy is more suitable at shorter duration and represents the case where economy displays disequilibrium behavior immediately after disaster as already alluded to by Dacy and Kunreuther (1969). At the shorter duration the investment to new capital might not be feasible to carry out and thus prompts to the latter strategy. The reasons for infeasible investments at the short run are disproportionally high transaction costs and non-convexities of investment commodities. It is quite safe to say that for typical epidemic case we are to investigate, the latter short run strategy is clearly more realistic portrayal of firm behavior. Additionally, as the firms do not know the duration for sure, they are even more likely to behave non-optimally. Therefore Dacy and Kunreuther's proposition for the role of public information seems adequate.

Let us look more closely to consequences of both of the strategies. We utilize the basic Solow-Swan growth model which can illuminate both of the cases. This model is convenient for this purpose as it describes macroeconomic changes and assumes technological change exogenous to the economy. In our case the adverse effect of the epidemic is conveniently seen as exogenous effect affecting productivity of economy. The production function is defined as:

$$Y(t) = F\big(K(t), A(t)L(t)\big), \quad (22)$$

where Y denotes output, K capital, L labor and t time. A is technology parameter that augments labor.[9] We get the convenient intensive form of the function by dividing it by the effective labor AL:

$$\frac{Y(t)}{A(t)L(t)} = F\left(\frac{K(t)}{A(t)L(t)}, 1\right) \rightarrow y(t) = f(k). \quad (23)$$

[9] This is the case of Harrod-neutral or labor-augmenting technological change. Macroeconomic stylized fact tells us that all technological change is labor-augmenting in the long run as the capital-output ratio has not displayed upward or downward trends in empirical studies.

Production function is assumed to satisfy $f(0) = 0$, $f'(k) > 0$, and $f''(k) < 0$. Let us denote rate of change in labor, $\frac{\dot{L}(t)}{L(t)} = n$ and rate of change in technology as $\frac{\dot{A}(t)}{A(t)} = g$. By using capital accumulation equation $\dot{K}(t) = sY(t) - \delta K(t)$, where s is savings rate and δ depreciation rate we get the core equation in Solow-Swan model:

$$\dot{k}(t) = sf\big(k(t)\big) - (n + g + \delta)k(t), \tag{24}$$

which is useful for examining the basic dynamic properties of the model. The model converges to balanced growth path where $\dot{k}(t) = 0$ and thus for the steady state level of effective capital we have

$$k^* = \frac{sf(k)}{n+g+\delta}. \tag{25}$$

Actualization of an epidemic risk causes the labor productivity growth rate g to decrease to level g_e. For convenience, we assume that s, n and δ stay unaffected. Output changes as well as lower productivity enters formula (26):

$$y_e(t) = f_e(k) = \frac{A_e(t)}{A(t)} f(k) < f(k) \tag{26}$$

where subscript e denotes epidemic. Therefore the steady state of capital accumulation after decrease in productivity is:

$$k_e^* = \frac{sf_e(k)}{n+g_e+\delta}. \tag{27}$$

The new level of capital use per capita can be higher or lower than before the epidemic level.[10] Let us take a look at both cases diagrammatically. In these figures we present capital use per capita and savings share of output as axis. Line presenting capital use growth is straight line that in the steady state coincides with investment share of output. In Figure 1 we see the case where $k_e^* > k^*$. The economy shifts from normal (N) steady state to one that represents epidemic in case 1 (E_1).

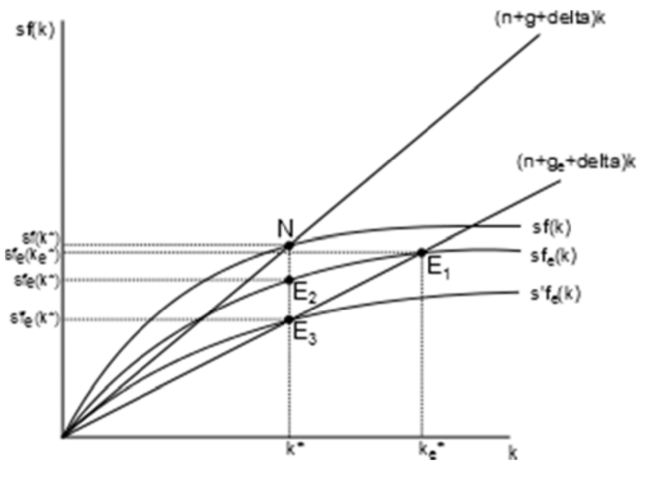

FIGURE 1. SOLOW MODEL STEADY STATE WITH DECREASING LABOR PRODUCTIVITY, $k_e^* > k^*$.

[10] $k_e^* \lesseqgtr k^*$ when $\dot{A}_e + A_e(n+\delta) \lesseqgtr \dot{A} + A(n+\delta)$.

A decrease in productivity increases capital stock per effective labor and economy becomes more capital intensive. Naturally the total output decreases as well as its primary factor base is less productive due to epidemic. From the figure 1 we see that effective output decreases. Now let us assume that the firms do not adjust their capital stock but maintain it during the epidemic as we already speculated that would be realistic for short run epidemics. The economy moves from steady state (N) to non-steady state epidemic case 2 depicted by dot E_2 in Figure 1. At this point more savings are accumulated than prevailing capital use would demand. Thus, the economy displays disequilibrium behavior in the short run. In order to maintain the steady state we allow savings rate to adjust from s to s'. In the case where $k_e^* > k^*$the savings rate shifts down and new steady state is found at E_3. Figure 2 presents the case of productivity decrease which leads to less capital intensive steady state. The savings rate would adjust upwards. The situation is otherwise analogous to the previous.

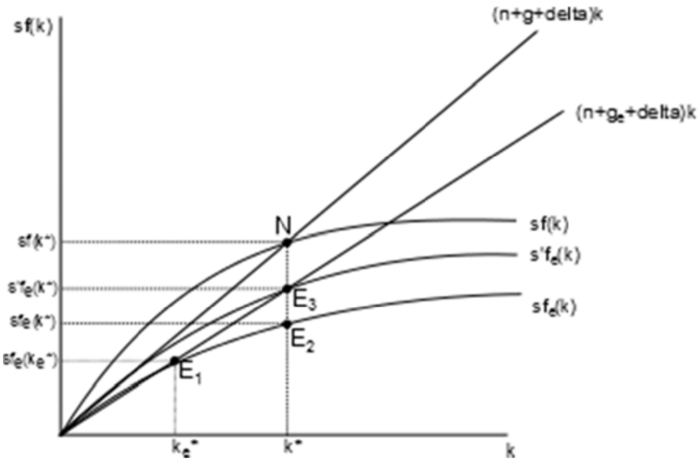

FIGURE 2. SOLOW MODEL STEADY STATE WITH DECREASING LABOR PRODUCTIVITY, $k_e^* < k^*$.

RECOVERY PROCESS

The return of labor productivity to its normal, non-epidemic level is the initial change in the economy after the epidemic subsides. The recovery path is of course rather different whether we consider adjusting or fixed capital case and Figure 3 and Figure 4 illustrate the situation. If the effective capital fully adjusts, output will be determined by that epidemic level k_e^*. The output level overshoots normal productivity level (dot R in Figure 3) or falls short of it (dot R in Figure 4), depending on whether capital use shifts up or down. In upwards adjusting capital case the savings rate s is not enough to maintain the level of effective capital k_e^*, which gradually begins to decrease to the original steady state level k^*. For the case of downwards adjusting capital, opposite holds. In the case that firms keep their capital fixed, the recovery process is simpler as the effective capital is already at the steady state level. Now the savings rate shifts from s' back to s.

Although the adjustment to steady state level capital use might seem to be desirable from economic theory point of view and an efficient feature of working market economies, we can note that the fixed capital case might have less to adjust in the first place and smaller adjustment related inefficiency costs as a result. However, further investigation requires more advanced simulation techniques to which we will return later on in the paper.

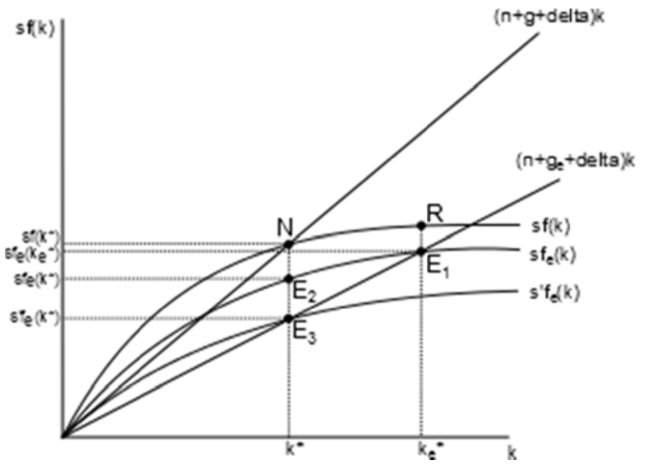

FIGURE 3. SOLOW MODEL AND RECOVERY PROCESS, $k_e^* > k^*$.

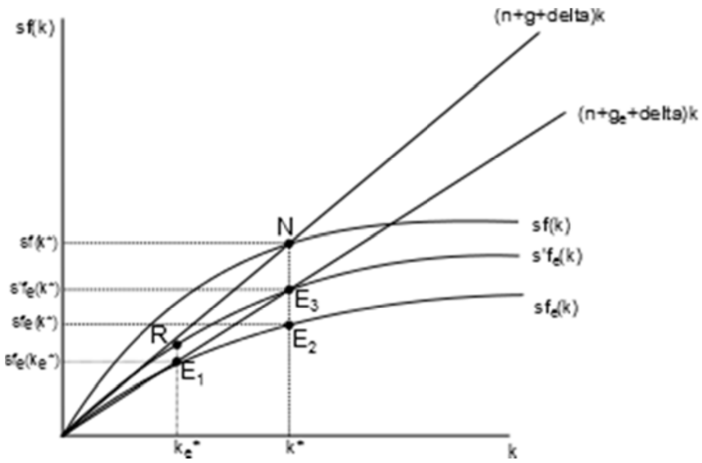

FIGURE 4. SOLOW MODEL AND RECOVERY PROCESS, $k_e^* < k^*$.

3. MATERIAL AND METHODS

As economic problems are typically complex, it makes sense to use modeling techniques in order to analyze them consistently. Hallegatte and Przyluski (2010, p. 16) list five main types of economic models that have been used to assess the effects of natural hazards: microeconomic models at the household level, econometric models at the local or national level, input-output (IO) models at regional and national level, applied general equilibrium (AGE)[11] models at regional or national level and network-production system models. Reggiani and Nijkamp (2004) have also suggested self-organized criticality (SOC) as modeling concept for evaluating hazards that could potentially lead economy to chaotic growth path. However, no operationalization to applied work exists yet. Next we will give a short summary for each of the methods and their relative shortcomings and merits.

[11] Alternative name, computable general equilibrium (CGE) is also widely used.

Household level microeconomic models are partial equilibrium mathematical constructions of an imaginary hazard infested households based on microeconomic theory. Their applicability is restricted to draw inferences on the household level behavior during a hazard and cannot be readily extrapolated to larger economic systems. The econometric models are based on statistical methods and they rely on relatively large historical databases. Although econometric models are commonly used for analyzing economic phenomena, they are not well suited for studying rare, mostly unanticipated events. It is highly doubtful whether analysis based on time series data that does not contain extreme effects could be extrapolated to hold in cases of such events. With hazards of relatively modest size, it is doubtful whether empirical evidence would turn out to be statistically significant. Furthermore, the econometric modeling cannot easily incorporate a priori information about the structure of the economy that would be crucial for identifying potential bottlenecks. The conclusions about economic consequences of natural disasters based on econometric studies are mixed.

The IO-models have fared better. They are based on the input-output data of an economy and thus easily incorporate information about economic structure. In a typical IO-model, the production is modeled as fixed shares of inputs. Therefore, the effects that are small by magnitude might cause huge overall effects in total output in such models. This inflexibility is inherent to IO-models and generally deemed as unrealistic feature. In other words there is no substitutability between the crucial inputs although the empirical evidence points otherwise: the relative shares of inputs are subject to change due to changes in prices. As there is inherent limitation for production adjustment in IO-models, an IO-analysis typically produces unnecessarily pessimistic results. However, the shorter the duration of an event, the more inflexible the economy is to adjust and thus for very short timeframe effects the IO-models might produce sensible results. But for dynamic analysis that aims at investigating the recovery process as well, IO-models are clearly not suitable tools. Furthermore, the IO-models are unrealistic as they do not incorporate resource constraints. This feature could make IO-modeling analysis unrealistically optimistic in some of the cases.

The AGE models can be seen as the state of the art economic models in applied economic research and they can address the both aforementioned IO-model shortcomings. AGE models are based on general equilibrium theory that has price mechanism as the prime mechanism for allocating the resources. The inputs are substitutable by an empirically derived magnitude of ease, elasticity of substitution. Therefore, if some factor of production can be substituted with another, this is typically modeled in AGE framework. Resource constraints are easily incorporated as well. However, although AGE models have many desirable features in comparison to the other modeling techniques, it has some shortcomings of its own that need to be particularly addressed in the context of hazard analysis. The AGE models might be overly flexible in contrast to IO-models. This can be severe shortcoming especially if we are dealing with short duration extreme events. One possible way to address this problem is to decrease the flexibility of the model by applying lower elasticities of substitution in shorter timeframe dynamics. More adequately, the flexibility problem could be addressed by model closure rules.

Although there is not a single optimal modeling approach to our problem, the AGE modeling framework has one additional convenience that finally makes it our favored choice of method. Indeed, one of the strengths of AGE modeling is its generality: it complies with various problems by proper adjustment. With careful fine-tuning, an AGE model can be set to function as I/O-model in the short run. This requires using non-conformist time frequencies and accordingly adjusted model parameterization and closure rules for the distinct phases of the hazard. This adjustment requires appropriate a priori information and data about the likely unfolding of an epidemic. We next turn to the model we use and the special tweaks we needed to apply in order to realistically analyze economic consequences of an epidemic.

We use a dynamic regional general equilibrium model VERM (VATTAGE Regional Model) for our analysis. It is multi-regional model of Finland where the country is divided to 19 regions.[12] The most recent database is based on 2008 national input-output table which is split to regions by gravity based method developed by Horridge et al. (2005). The database has new functionality of flexible industry, commodity and regional aggregation. Our problem clearly benefits from the flexibility as we can concentrate on the regions and industries that are most prominent for our problem and thus considerably save in implementation time. The model database aggregation is [will be] presented in the appendix along with the most relevant parameter values used in our simulations. The basic description of the VERM model is Honkatukia (2013).

Rose & Guha (2004) analyzed earthquakes with a static AGE model. They ran several simulations for different timeframes by using lower flexibility specifications for shorter run effects in order to compare the results for typical AGE analyzes of such disasters. The shortest timeframe was less than seven days after the hazard and the long run incorporated full adjustment of capital stock after the disaster. Their simulation specifications were as follows (2004, pp. 125-127):

- very short run (<= 7 days) – very low input and import elasticities
- short run (<= 6 months) – low input elasticities but very high import elasticities (in absence of transport network disruptions)
- medium run (<= 1 year) – normal elasticities + inventory replenishment
- long run – qualitative changes in capital stock ("creative destruction") + new, increased level of mitigation measures

They found expectedly that the models that fully acknowledged the adjustment difficulties an economy faces during a hazard resulted in more negative overall results. Thus, more careful modeling of the adjustment process will give more accurate view on the economic impacts and consequently to the appropriate mitigation level.

Dixon et al. (2010) analyzed hypothetical H1N1 influenza epidemic in U.S. with USAGE that is a dynamic AGE model for USA. The novelty in their approach was to use quarterly dynamics instead of typical yearly mode. Thus, they could target the impact of the epidemic more precisely to its duration. More severe impact on short time disrupts economy more severely than equal impact distributed more evenly throughout the time. Their model also included excess capital use which was introduced in AGE modeling by Dixon and Rimmer (2011). Excess capital use most closely incorporates in AGE model the strategy where the firms do not adjust their capital use in traditional AGE modeling sense. Actually they do adjust their capital use but allow some excess capacity to exist during the epidemic. They

[12] The NUTS3 regional classification.

modeled four separate effects to the economy: 1) reduction in tourism, 2) decreased productivity, 3) increased demand for health care services and 4) decreased spending in leisure activities. They found that the effects are quite severe during the peak of epidemic and that the demand side effects (the detrimental impacts on tourism as the overbearing effect) have stronger and longer reaching consequences than the supply side effects do.

For our study we adopt from Dixon et al. (2010) the shorter than year timeframe and excess capacity of capital use. Our main extensions are the examination of regional effects of a spatially restricted hazard and valuation of the optimal mitigation investment.

4. RESULTS

BACK-OF-THE-ENVELOPE FRAMEWORK

We investigate the properties of negative productivity shock in our regional AGE model with back-of-the-envelope calculation. Back-of-the-envelope (bote) calculations are simple calculations with the model's core macro level equations. They are very useful for revealing the underlying mechanisms in the model that determine the final outcome. They can also point to potential errors. They abstract from all the industry and commodity level details that computationally intensive AGE model delivers. Before commencing with actual AGE model simulations, the bote calculations are useful guides for the model closure rules and other fine-tuning. As starting point we use the framework of Dixon and Rimmer (2011) with excess capacity of capital. When productivity drops, the firms adjust their capital in use (KU) that is a fraction of capital in existence (KE). Our back-of-the-envelope model has three core equations:

(28) $$\frac{W}{P_c} = \frac{P_G}{P_c} MPL\left(\frac{KU}{AL}\right)$$

(29) $$Y = F(KU, AL)$$

(30) $$Y = C + I + G + X - M$$

Equation (28) tells that the nominal wage rate is a function of marginal product of labor (MPL). In other words, we assume nominal wage rigidities in our model. Decrease in productivity decreases the use of effective labor AL. We assume that as the nominal wage rate is fixed at the very short run, the capital in use decreases by the same amount as the effective labor. Equation (29) is the production function that is homogenous of degree one. As both effective labor and capital in use decrease by the same rate, we see the equal rate of decrease in output (Y). Equation (30) is the familiar expenditure side decomposition of GDP.

In our model baseline we assume that household consumption (C) follows closely the output. However, in the hazard case we assume that the temporary dip in output does not affect household consumption that stays at the baseline level.[13] The government expenditure (G) is even more constant in the very short time frame but we predict an

[13] Changes in household consumption are likely at least what comes to composition. Consumption of some commodities like medicines and services like health care, will probably increase due to hazard. On the other hand some other commodities like leisure related services are probably

increase due to hazard related expenses such as increased demand for health care services. The exports decrease as much as the regional output. Finally, the imports adjust accordingly and we assume that the share between domestic and foreign imports stay constant.

The change in investments (I) is affected by the rental rates of capital. Equations (31)-(32) and complementarities (33)-(36) determine the excess-capacity specification:

(31) $$\left\{\frac{Q(t)}{Q_b(t)} - 1\right\} = \left\{\frac{Q(t-1)}{Q_b(t-1)} - 1\right\} + \alpha_1 \left\{\frac{KU(t)}{KE(t)} - 1\right\} + S(t)$$

(32) $$Q(t) = n(KU(t), \dots)$$

(33) $S(t) = 0$ for $t < t_c$

(34) $S(t) \geq 0$ for $t = t_c$

(35) $KU(t) = KE(t)$ for $t \geq t_c$

(36) $KU(t) \leq KE(t)$ for all t

Rental rates (Q) deviate from the baseline situation (Q_b) according to equation (32). It is determined by previous year's deviation and fraction of excess capacity. α_1 is positive parameter and $S(t)$ is a slack variable.

Investments' ratio to capital in existence is determined by

(37) $$\frac{I(t)}{KE(t)} - D = f[EROR(t), H(t)] - \alpha_2 \left[1 - \frac{KU(t-1)}{KE(t-1)}\right]$$

and expected rate of return as

(38) $$EROR(t) = \left[\frac{KU(t)}{KE(t)}\right] * g[Q(t), \dots] - \left[1 - \frac{KU(t)}{KE(t)}\right] * D$$

The productivity decrease affects the investments by two ways, first via expected rate of return (EROR) and second by allowing the use of some of the excess capital not used during the previous period. f is a function of EROR and g is function of rental rate. We assume them both to be homogenous of degree one. The parameter α_2 is the fraction of previous period's excess capacity that is still usable. For a very short period, we find it reasonable to apply quite large value for α_2. These two effects work in opposite direction, expected rate of return increases after capacity disuse and the unutilized capacity dampens the need for new investments. We can also note that the dampening effect starts to have effect only at the first period after the hazard.

Next, let us think about the spatial aspects of the analysis. We divide the expenditure side GDP equation to two regions, hazard (h) and non-hazard (nh):

(39) $$Y = Y^H + Y^{NH}$$

(40) $$Y^H = C^H + I^H + G^H + (X_{dom}^H - M_{dom}^H) + \left(X_{for}^H - M_{for}^H\right)$$

(41) $$Y^{NH} = C^{NH} + I^{NH} + G^{NH} + (X_{dom}^{NH} - M_{dom}^{NH}) + \left(X_{for}^{NH} - M_{for}^{NH}\right)$$

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demanded less during the hazard. That leaves the change in consumption ambiguous and subject to further assessment. Assumption of steady household consumption during the hazard is good approximation for our back-of-the-envelope model.

Based on the previous calculations, the Δ_A^N productivity decrease perturbs the hazard region GDP to

$$\Delta_A^H * Y^H = C^H + \Delta_I^H * I^H + \Delta_G^H * G^H + (\Delta_A^H * X_{dom}^H - \Delta_M^H * M_{dom}^H) + \left(\Delta_A^H * X_{for}^H - \Delta_M^H * M_{for}^H\right) \tag{42}$$

The productivity shock directly affects the output and the exports. We assume no change for household consumption and an increase in government spending. Next we calculate the change in investments due to productivity decrease. First we calculate deviation in rental rates, apply the result to calculate the expected rate of return and finally the deviation in investments. We calculate the investment deviations with these three equations:

$$\Delta_Q^H = 1 + \alpha_1 * \Delta_A^H \tag{43}$$

$$\Delta_{EROR}^H = (1 - \Delta_A^H) * \Delta_Q^H - \Delta_A^H * D \tag{44}$$

$$\Delta_I^H = \Delta_{EROR}^H - \alpha_2 * \Delta_{A,-1}^H \tag{45}$$

We assume that government expenses remain as before save some extra spending needed due to hazard. Thus, there is deviation in government spending, $\Delta_G^H \geq 1$. Finally, the deviations in imports (Δ_M^H) absorb the negative effects:

$$\Delta_A^H * \left(Y^H - X_{dom}^H - X_{for}^H\right) - (C^H + \Delta_I^H * I^H + \Delta_G^H * G^H) = -\Delta_M^H * \left(M_{dom}^H + M_{for}^H\right) \tag{46}$$

$$\frac{\Delta_A^H * \left(Y^H - X_{dom}^H - X_{for}^H\right) - (C^H + \Delta_I^H * I^H + \Delta_G^H * G^H)}{M_{dom}^H + M_{for}^H} = -\Delta_M^H \tag{47}$$

For the rest of the country, the non-hazard region experiences decline in their domestic trade. The domestic trade needs to balance and so the change in hazard region exports equals the change in non-hazard region imports and vice versa. The output in the non-hazard region changes by the same amount as its domestic exports.

$$\Delta_{X,dom}^{NH} * Y^{NH} = C^{NH} + \Delta_I^{NH} * I^{NH} + \Delta_G^{NH} * G^{NH} + \left(\Delta_{X,dom}^{NH} * X_{dom}^{NH} - \Delta_{M,dom}^{NH} * M_{dom}^{NH}\right) + \Delta_{for}^{NH} * \left(X_{for}^{NH} - M_{for}^{NH}\right) \tag{48}$$

where

$$\Delta_{X,dom}^{NH} = 1 + \frac{\Delta_M^H * M_{dom}^H}{X_{dom}^{NH}} \tag{49}$$

$$\Delta_{M,dom}^{NH} = 1 + \frac{\Delta_A^H * X_{dom}^H}{M_{dom}^{NH}} \tag{50}$$

The total output changes by the same amount as the domestic exports. This has consequences for the total output change depending on $\Delta_{X,dom}^{NH}$. If $\frac{\Delta_M^H * M_{dom}^H}{X_{dom}^{NH}} > 0$, then the non-hazard region output increases and $\Delta_Y < \Delta_A^H$ and the hazard effects are damped by the domestic trade. In the opposite case when $\frac{\Delta_M^H * M_{dom}^H}{X_{dom}^{NH}} < 0$, we have that $\Delta_Y > \Delta_A^H$ and total output loss is greater than the productivity decrease in the hazard region. Investments at the non-hazard region change as well. The non-hazard region can have excess capacity if their output were to decrease. It is also realistic to assume that government expenses increase in all of the regions as both central and local governments contribute to expenses. We assume here for simplicity that the half of the increase in government expenses is covered by the local government at the hazard region, and the rest by the central government. We can quite safely assume that the effects to the rest of the world are negligible and the foreign trade balance finally adjusts by Δ_{for}^{NH}.

Few calculations illustrate the regional effects of negative productivity shock based on back-of-the-envelope calculations with real data. We parameterize the back-of-the-envelope model by letting $\alpha_1 = 0.3$, $\alpha_2 = 0.9$ and depreciation rate $D = 0.2$. We calculate different levels of productivity decrease from 1 to 10 %. First, we calculate the effects of the shock for our study region Varsinais-Suomi that is net domestic exporter, largely due to fuel refining industry activities located in the region. Next we do the same calculations for another region Pirkanmaa that is net domestic importer in order to see the difference the domestic trade position makes. Varsinais-Suomi and Pirkanmaa closely resemble each other in terms of economic activity as their net regional outputs are 15.5 and 16 billion euros, respectively.

Static calculations

Figure 5 shows the deviations in GDP for both regions. In the net exporting case of Varsinais-Suomi, we see that the output at the whole country level decreases more than the hazard related productivity decrease. The 10 % productivity decrease implies 1.05 % and 0.2 % decrease in national and non-hazard region GDPs, respectively. The multiplier of the negative effect is 1.22 and is fairly constant for all the levels of productivity decrease. On the other hand in the net importing case of Pirkanmaa, the effects are markedly different as 10 % productivity decrease at the hazard region causes only 0.86 % decrease and 0.02 % increase in the national and non-hazard region GDPs, respectively. The multiplier is 0.98. Multiplier being less than one means that slight output improvement at the non-hazard region compensates some of the losses in the hazard region. Therefore the qualitative results seem to be dependent on the domestic trade position of the hazard region.

Figure 6 shows the deviation in investment levels for both regions. The results are, not surprisingly, similar with the GDP results. The investments decrease in Varsinais-Suomi by 7.5 % after 10 % productivity decrease in the hazard region. At the national level, the investments decrease by 0.7 % and at the non-hazard by 0.15 %. For Varsinais-Suomi we see a decrease by 7.5 % at the hazard region, 0.5 % nationally and 0.01 % increase in the non-hazard region. For dynamic considerations this has obvious consequences as when the investments decrease, the capital in existence will grow less rapidly when compared to baseline.

Figure 7 displays the changes in net export volumes for both regions. In the net exporting case the domestic trade decreases by 100 million euros, which is 1.6 % of the total domestic trade. We also see that the total net foreign exports decrease by almost 200 million euros, which is 31 % of total foreign net exports and 2.9 % of the total exports. In the net importing case the domestic trade decreases by 83 million euros which is 0.9 % of total domestic trade. Net foreign exports decrease by 165 million euros which is 26 % of the total net exports and 2.4% of total exports. Thus we see that the trade situation deteriorates more when the affected region is net domestic exporter.

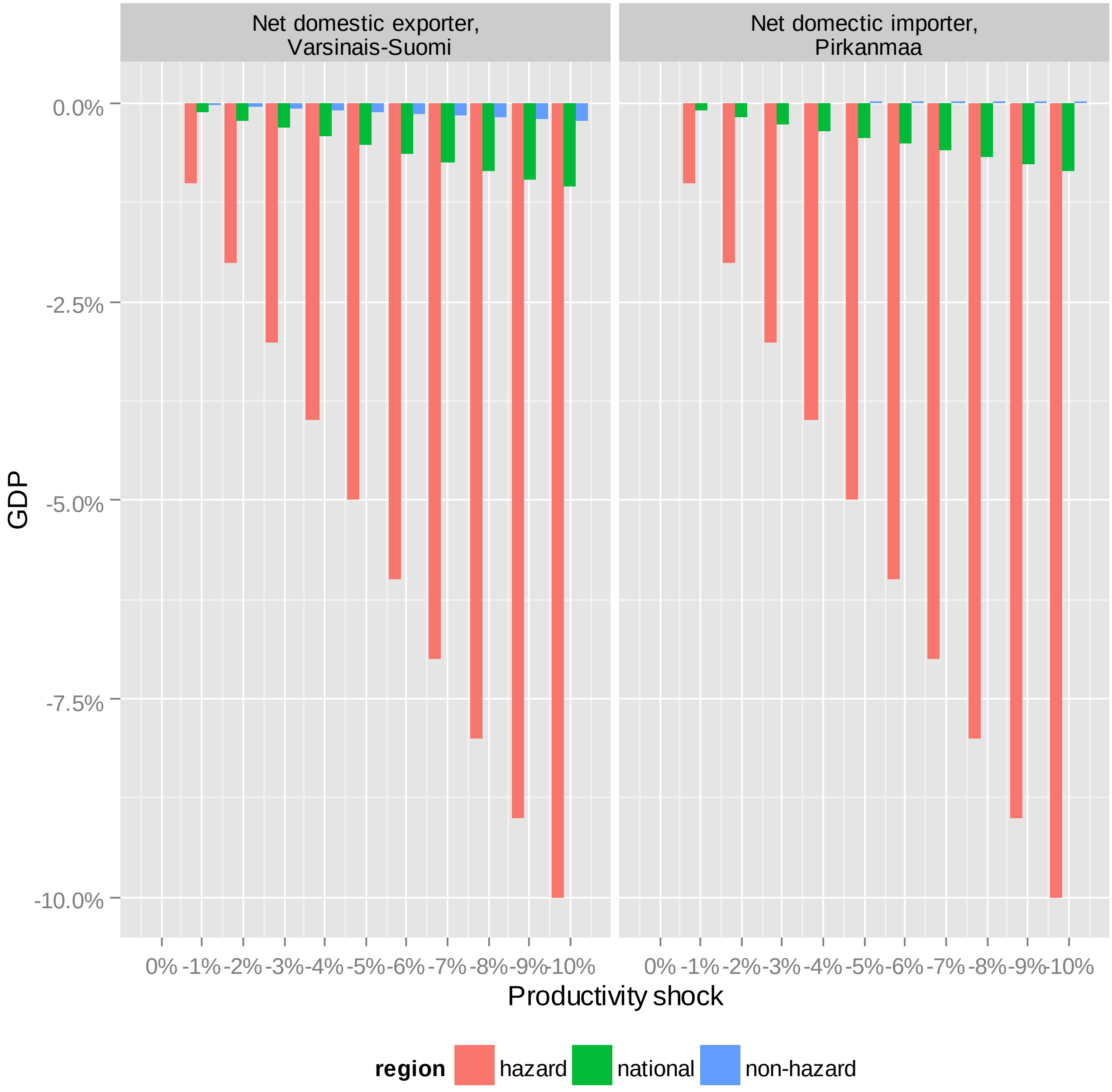

FIGURE 5. OUTPUT CHANGE AT DIFFERENT PRODUCTIVITY LEVELS.

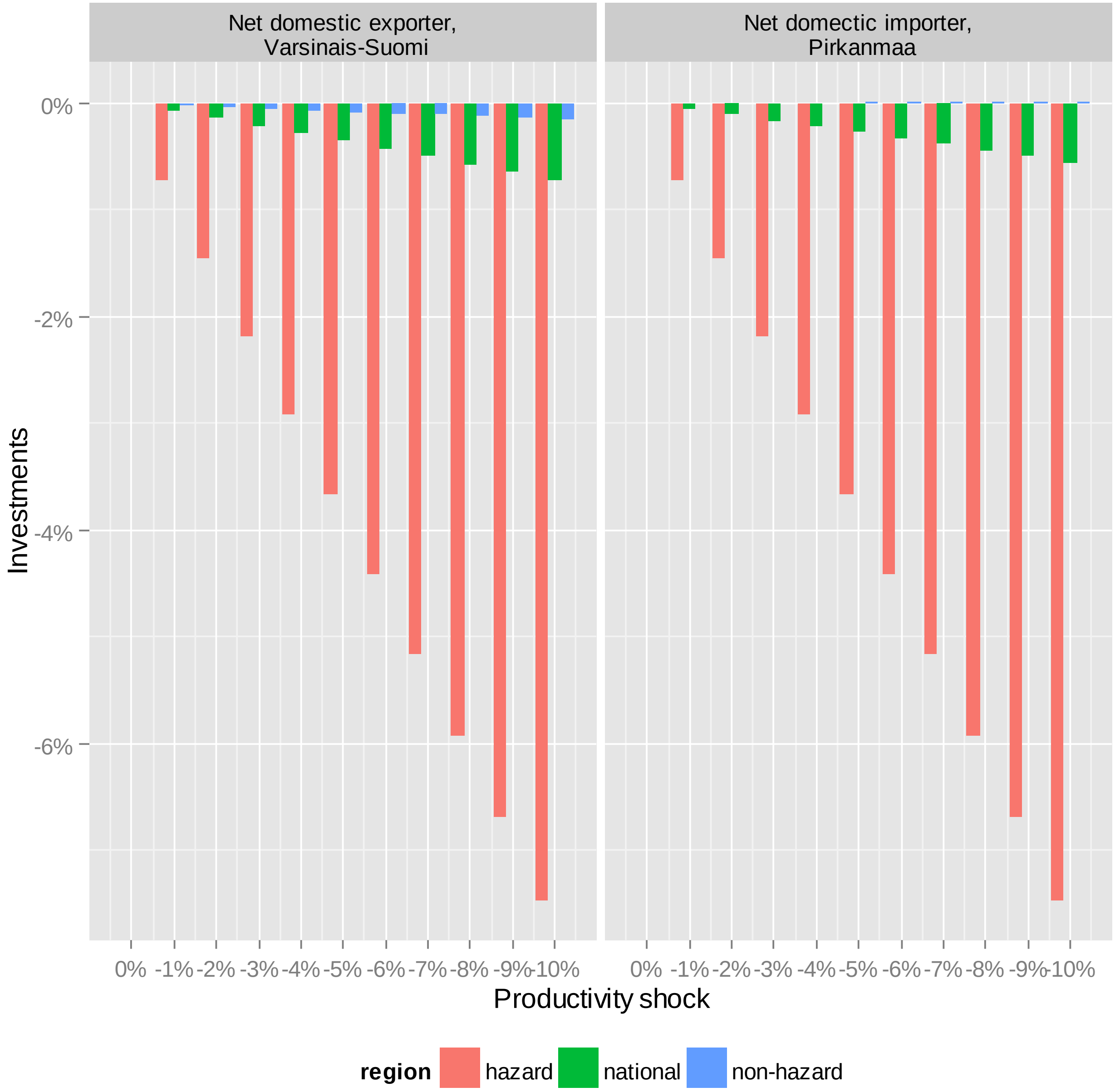

FIGURE 6. INVESTMENT CHANGE AT DIFFERENT PRODUCTIVITY LEVELS.

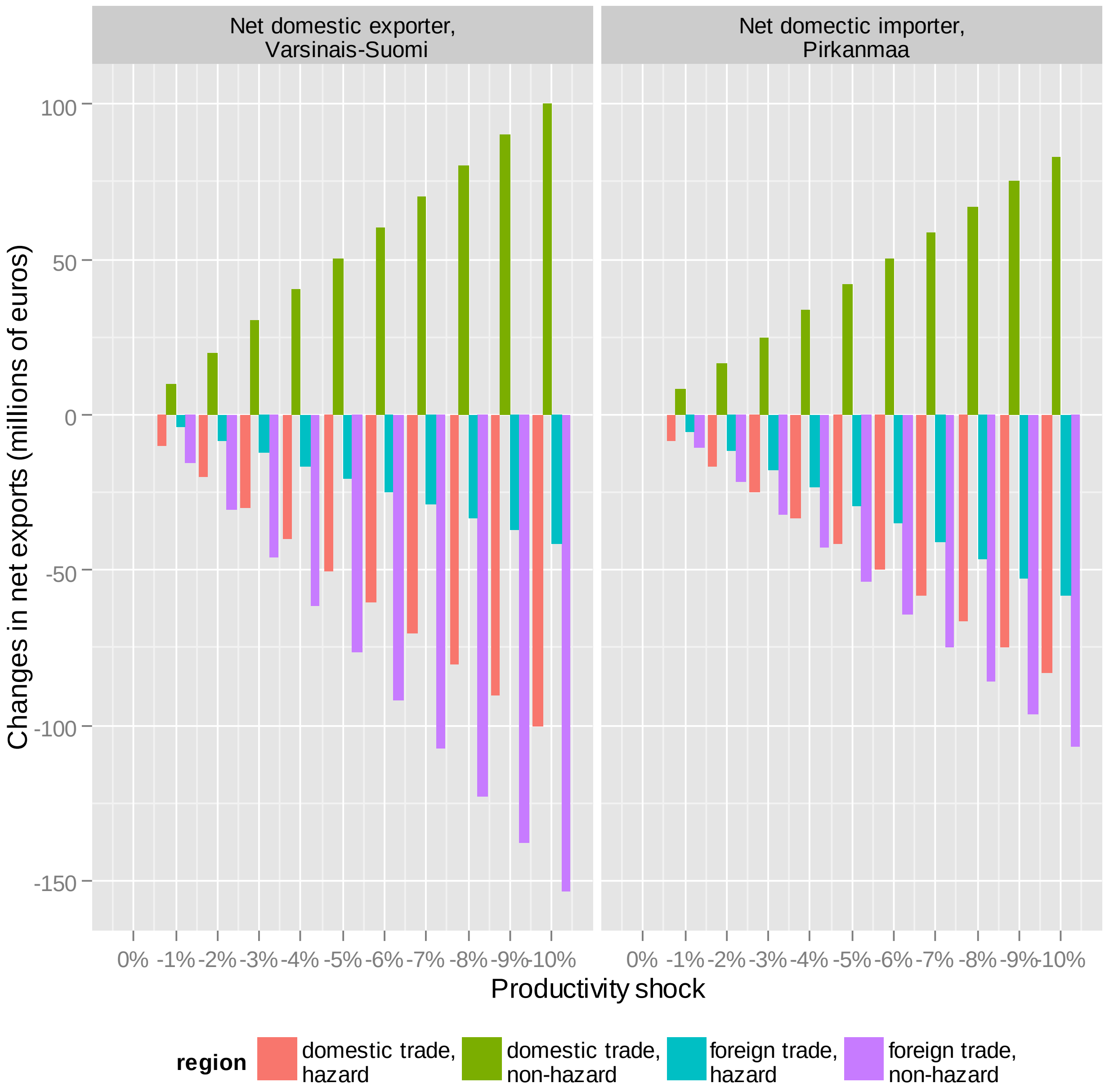

FIGURE 7 CHANGES IN NET EXPORTS.

DYNAMIC CONSIDERATIONS

Our back-of-the-envelope calculations sheds light on how an economy will adjust to a productivity shock in a regional AGE model during the hazard. Additionally, this adjustment process has longer term effects as well. There are two main effects that keep accumulating the costs of the hazard after it has subsided: the lower level of capital in existence and increased foreign trade debt. Next we consider some dynamic implications of the back-of-the-envelope results. For simplicity, we assume that at the subsequent period, the productivity returns to the pre-hazard level. The capital in use returns immediately back to the level of capital in existence. As the investments decreased during the hazard, the subsequent capital in existence will be lower than in the baseline. We handle the transition to post-hazard economy by allowing employment to adjust to a new level. The nominal wage as presented in equation (28) adjusts to the new, lower than baseline level of capital in existence. There will thus be lower than baseline level of employment immediately after the hazard. With wage rigidities, the adjustment process lags behind somewhat.

The hazard region invested less during the hazard, which means that its capital in existence will negatively deviate from the baseline in the period after the hazard. This holds true for the non-hazard region as well in the case that the hazard region is net domestic exporter. However, simple calculations show that the deviation is small – 10 % productivity shock in net domestic exporting region causes only 0.05 % reduction in the region's capital stock when compared to baseline. Thus the adjustment for such a shock is swift in AGE model and resulting decrease in employment is small enough to go unnoticed. This seems quite realistic.

Figure 7 summarized the effects in trade. We see that in all cases the hazard and non-hazard regions incur foreign trade deficit during the hazard. Thus the terms of trade deteriorates due to hazard. We find this deterioration only as temporary phenomenon after which the economy gradually shifts closer to its original level which it might not however completely achieve. We also saw that government increased its spending and it thus incurs deficits during the hazard. We will assume that at some time interval the government deficits will be balanced back to the level of the baseline. This balancing act will of course decrease output and consumption.

5. Discussion

Our results have thus far shown that for assessing mitigation action's costs and benefits spatial dimension counts; some regions difficulties have more potential to cause harm to other regions' economies. Analysis by full regional AGE model will further shed light by incorporating industry level detail and full dynamic adjustment process. Careful fine-tuning of an AGE model to portray the actions during the hazard and the adjustment process afterwards are tantamount for finding realistic magnitude of the costs.

6. Conclusion

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