CONHAZ

Costs of Natural Hazards

Indirect Costs of Natural Hazards

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Abstract

Large-scale disasters regularly affect societies over the globe, causing large destruction and damage. After each of these events, media, insurance companies, and international institutions publish numerous assessments of the “cost of the disaster.” However these assessments are based on different methodologies and approaches, and they often reach different results. Besides methodological differences, these discrepancies are due to the multi-dimensionality in disaster impacts and their large redistributive effects, which make it unclear what

is included in the estimates. But most importantly, the purpose of these assessments is rarely specified, although different purposes correspond to different perimeters of analysis and different definitions of what a cost is. To clarify this situation, this paper proposes a definition of the cost of a disaster, and emphasizes the most important mechanisms that explain and determine this cost. It does so by first explaining why the direct economic cost, that is, the value of what has been damaged or destroyed by the disaster, is not a sufficient indicator of disaster seriousness and why estimating indirect losses is crucial to assess the consequences on welfare. The paper describes the main indirect consequences of a disaster and the following reconstruction phase, and discusses the economic mechanisms at play. It proposes a review of available methodologies to assess indirect economic consequences, illustrated with examples from the literature. Finally, it highlights the need for a better understanding of the economics of natural disasters and suggests a few promising areas for research on this topic.

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1. Introduction

Large-scale disasters regularly affect societies over the globe, causing huge destructions and damages. The 2010 earthquake in Port-au-Prince and the hurricane Katrina in 2005 have shown that poor as well as rich countries are vulnerable to these events, which have long lasting consequences on welfare, and on human and economic development.

An obvious illustration of why indirect losses are important is the difference between scenarios with various reconstruction paces. In terms of welfare, there is a large difference between, on the one hand, a scenario in which all direct losses can be repaired in a few months thanks to an efficient reconstruction process and, on the other hand, a scenario in which reconstruction is inefficient and takes years. For the same amount of direct losses, welfare impacts are much larger in the latter case, and this should be taken into account.

After each of these events, media, insurance companies and international institutions publish numerous assessments of the “cost of the disaster.” However these various assessments are based on different methodologies and approaches, and they often reach quite different results. Beside technical problems, these discrepancies are due to the multi-dimensionality in disaster impacts and their large redistributive effects, which make it unclear what is included or not in disaster cost assessments. But most importantly, the purpose of these assessments is rarely specified, even though different purposes correspond to different perimeter of analysis and different definitions of what a cost is.

This confusion translates into the multiplicity of words to characterize the cost of a disaster in published assessments: direct losses, asset losses, indirect losses, output losses, intangible losses, market and non-market losses, welfare losses, or any combination of those. It also makes it almost impossible to compare or aggregate published estimates that are based on so many different assumptions and methods.

To clarify the situation, this background paper proposes a definition of the cost of a disaster, and emphasizes the most important mechanisms that explain this cost. It does so by first explaining why the direct economic cost, i.e. the value of what has been damaged or destroyed by the disaster, is not a good indicator of disaster seriousness and why estimating indirect losses is crucial. Then, it describes the main indirect consequences of a disaster and of the following reconstruction phase, and discusses the methodologies to measure them. Finally, it proposes a review of published assessments of indirect economic consequences, which confirm their importance and the need to take them into account.

2. Compilation of the cost-assessment methods

2.1 The indirect cost of the natural hazards

2.1.1. What is a disaster? What is an indirect cost?

There is no single definition of a disaster. From an economic perspective, however, a natural disaster can be defined as a natural event that causes a perturbation to the functioning of the economic system, with a significant negative impact on assets, production factors, output, employment, or consumption. Examples of such natural event are earthquakes, storms, hurricanes, intense precipitations, droughts, heat waves, cold spells, and thunderstorms and lightning.

Disasters affect the economic system in multiple ways, and defining the “cost” of a disaster is tricky. Pelling et al. (2002), Lindell and Prater (2003), Cochrane (2004), Rose (2004), among others, discuss typologies of disaster impacts. These typologies usually distinguish between direct and indirect losses.

Direct losses are the immediate consequences of the disaster physical phenomenon: the consequence of high winds, of water inundation, or of ground shaking. Direct losses are often classified into direct market losses and direct non-market losses (also sometimes referred to as intangible losses, even though non-market losses are not necessarily intangible). Market losses are losses to goods and services that are traded on markets, and for which a price can easily be observed. Even though droughts or heat waves affect directly the economic output (especially in the agriculture sector), direct market losses from most disasters (earthquakes, floods, etc.) are losses of assets, i.e. damages to the built environment and manufactured goods. These losses can be estimated as the repairing or replacement cost of the destroyed or damaged assets. Since building and manufactured goods can be bought on existing markets, their price is known. Direct market losses can thus be estimated using observed prices and inventories of physical losses that can be observed (as recorded, e.g., in the EM-DAT database or insurance-industry databases) or modelled (using, e.g., catastrophe models of the insurance industry).

Non-market direct losses include all damages that cannot be repaired or replaced through purchases on a market. For them, there is no easily observed price that can be used to estimate losses. This is the case, among others, for health impacts, loss of lives, natural asset damages and ecosystem losses, and damages to historical and cultural assets. Sometimes, a price for non-market impacts can be built using indirect methods, but these estimates are rarely consensual (e.g., the statistical value of human life always leads to heated controversies).

Indirect losses (also labelled “higher-order losses” in Rose, 2004) include all losses that are not provoked by the disaster itself, but by its consequences. Different hazards communities have different seminal papers for defining indirect costs: Meyer and Messner (2005) and FLOODSite (2007) for floods; Wilhite (2000) and Wilhite et al. (2007) for droughts; and McInnes (2000) for coastal hazards. Contentious issues may emerge around the edge of these definitions across hazard communities: what are the limits between direct and indirect costs categories? In particular discussions often occur around the notion of losses due to business interruption, which can be included in direct losses or in indirect losses, or as a stand-alone category. For capital-destroying hazards (flood, earthquakes, storms), the term “indirect losses” is often used as a proxy for “output losses,” i.e. the reduction in economic production provoked by the disaster. Output losses include the cost of business interruption caused by disruptions of water or electricity supplies, and longer term consequences of infrastructure and capital damages.

To help identify indirect losses, we propose the following criteria. First, indirect losses are caused by secondary effects, not by the hazard itself. Indirect costs can be caused by hazard destructions or by business interruptions. In addition to this obvious criterion, costs are indirect if they are spanning on a longer period of time, a larger spatial scale or affecting a different economic sector than the disaster itself. Classification of hazards by scale and time effect is done by, e.g., Brown Gaddis et al. (2006), and Jonkman et al. (2008).

This definition1 is consistent with definitions from different hazard communities. It includes business interruption in direct losses (since their most classical definition makes them mainly short-term, during the hazard duration). Also, this definition avoids consistency problems for slow-onset hazards such as drought. With this definition, the reduction in agriculture yield, and in farmer income, are considered as direct costs, consistent with intuition, while the impacts on other economic sector trading with the agricultural sector are indirect costs.

Indirect losses can be market or non-market losses (see f.i., Government of Queensland, 2002). Sometimes, non-monetary indirect consequences of disasters are also included, like the impact on poverty or inequalities, the reduction in collected taxes, or the increase in national debt.

In more general terms, several issues are raised by the use of GDP change as an indicator to assess indirect losses. These issues are, among others, (i) the question of appropriate scale between the scale of the event and the scale of GDP measurement, (ii) the capacity of GDP to be a good proxy for welfare (see, e.g., CMEPSP, 2009; Council and European Parliament, 2009).

2.1.2. Definition and assessment purpose

These possible definitions of indirect losses create specific difficulties. For instance, indirect losses can have “negative-cost” components, i.e. gains from additional activity created by the reconstruction. Sometimes, non-monetary indirect consequences of disasters are also included, like the impact on poverty or inequalities, the reduction in collected taxes, or the increase in national debt.

[1] Questions on the boundaries of the different types of costs are discussed across the different background papers and benefit from a synthesis in the final report. It appears that for end users or practitioners this distinction is really theoretical. The main question for them is the capacity to determine costs that they are accountable for at their level.

Another difficulty in disaster cost assessment lies in the definition of the baseline scenario. The cost of the disaster has indeed to be calculated by comparing the actual trajectory (with disaster impacts) with a counterfactual baseline trajectory (i.e., a scenario of what would have occurred in absence of disasters). This baseline is not easy to define, and several baselines are often possible. Moreover, in cases where recovery and reconstruction does not lead to a return to the baseline scenario, there are permanent (positive or negative) disaster effects that are difficult to compare with a non-disaster scenario2.

For instance, a disaster can lead to a permanent extinction of vulnerable economic activities in a region, because these activities are already threatened and cannot recover, or because they can move to less risky locations. In that case, the disaster is not a temporary event, but a permanent negative shock for a region and it is more difficult to define the disaster cost. Also, reconstruction can be used to develop new economic sectors, with larger productivity, and lead to a final situation that can be considered more desirable than the baseline scenario. This improvement can be seen as a benefit of the disaster. It is however difficult to attribute unambiguously this benefit to the disaster, because the same economic shift would have been possible in absence of disaster, making it possible to get the benefits without suffering from the disaster-related human and welfare losses.

Most importantly, defining the cost of a disaster cannot be done independently of the purpose of the assessment. Different economic agents, indeed, are interested in different types of cost. Insurers, for instance, are mainly interested in consequences that can be insured. Practically, this encompasses mainly the cost of damages to insurable assets (e.g., damaged houses and factories), and short-term business interruption caused by the disaster (e.g., the impossibility to produce until electricity is restored).

For affected households, insurable assets are also a major component, but other cost categories are as important. Primarily, loss of lives, health impacts and perturbation to their daily life are crucial. But in addition, household are concerned about their assets but also about their income, which can be reduced by business interruption or by loss of jobs, and about their ability to consume, i.e. the availability of goods and services.

At the society scale, all these aspects are important, but local authorities, governments and international institutions are also interested in other points. First, to manage the recovery and reconstruction period and to scale the necessary amount of international aid, they need information on the aggregated impact on economic production, on unemployment and jobs, on the impact of inequality and poverty, on local-businesses market-shares, on commercial balance, on collected taxes, etc. Second, to assess whether investment in prevention measures are desirable, they need the broadest possible assessments of the total disaster cost to the population, i.e. an estimate of welfare losses.

[2] This question of recovery, trajectory and ultimately of sustainability is also addressed in the WP5 paper concerned with flood events.

Moreover, disaster impacts can have positive or negative ripple-effects at the global scale, as shown by hurricane Katrina, which led to a significant rise in world oil prices. Depending on the purpose and of the decision-making spatial scale, the perimeter of the cost analysis will be different. For instance, a country may want to assess the losses in the affected region, disregarding all out-of-the-region impacts, to calibrate the financial support it wants to provide to the victims. But it may also want to assess total losses on its territory, including gains and losses outside the affected region, for example to assess the impact on its public finance.

Clearly, depending on the purpose of the assessment, some of the cost components have to be included or not in the analysis. In the following, we focus on the economic cost for the affected region, with the aim of informing decision-makers on post-disaster financial aid and prevention measure desirability. To do so, it is obvious that the direct cost is an insufficient measure, and that the loss of welfare is much more relevant (see welfare effect assessments for droughts in Holden and Shiferaw (2004) and Brooker (1995)).

Assessing a loss of welfare is complicated, as it includes many economic and non-economic components. Here, we focus exclusively on the economic component of welfare losses, and we define the economic cost of disaster as the lost consumption, considered as an important component and a good proxy of economic-related welfare losses3. Of course, this background paper does not try to be comprehensive, and major cost components are left out of the analysis, like loss of lives, health consequences, and loss of jobs. These additional component are important for the population welfare and therefore for prevention measure assessments. But, to our understanding, indirect costs assessment done so as to focus on welfare losses are the only indicators to assess “the economic costs” of a disaster.

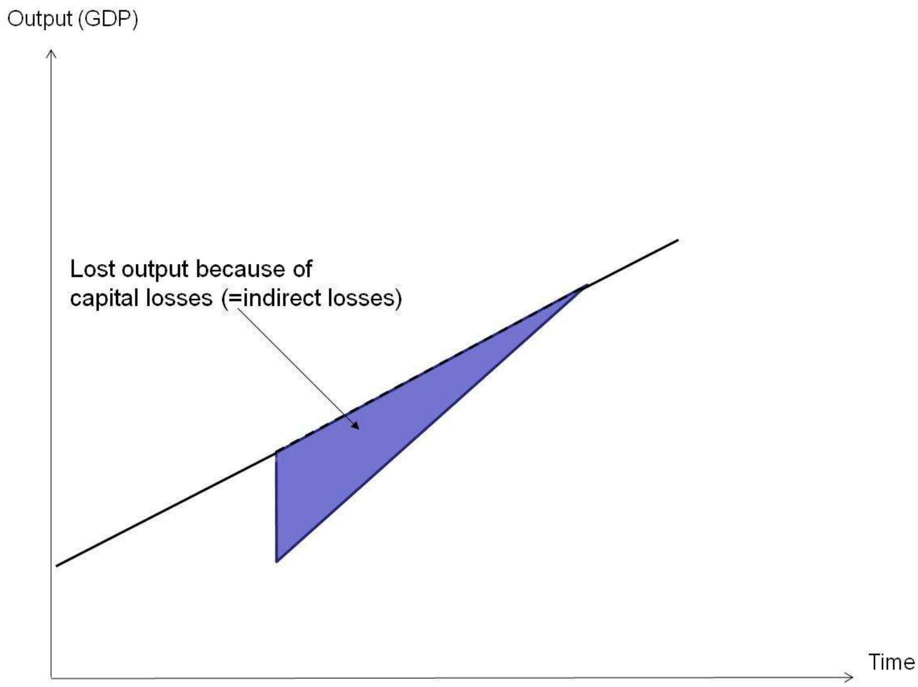
2.1.3 Consumption losses and output losses

This section explains how to assess consumption losses from asset and output losses. More precisely, it explains why the sum of asset losses and output losses is a good proxy for the loss of consumption. To do so, Fig. 1, (a), (b) and (c) show simplified representations of a post-disaster situation. Figure 1(a) depicts the situation in which only output losses are estimated, in which the disaster leads to a temporary reduction in output during the reconstruction phase. We assume here that reconstruction is a return to the baseline scenario (i.e. a no-disaster counterfactual scenario). As already stated, this is not always the case, but making an assumption on the final state is necessary to define the “cost” of the disaster, and the assumption of a return to the non-disaster baseline scenario is likely to be the most neutral one for this type of assessment.

The sum of instantaneous output loss is what is often referred to as the indirect loss. But reconstruction needs in the disaster aftermath means that a significant share of the remaining production will have to be devoted to reconstruction, as shown in Fig. 1(b). In other terms, the resources used to rebuild damaged houses cannot be used to build new houses, or to maintain

[3] In an utilitarist framework, what matters is not output and production, but consumption.

existing ones. This reconstruction output is included in total output, and is not a loss of output. But it is a "forced" investment, in addition to the normal-time investment—consumption trade-off. It causes, therefore, a loss of welfare. The value of this forced investment is the replacement value of damaged asset, i.e. what is referred to as the direct losses. This is what is represented in Fig. 1(c): the sum of the output loss and of the reconstruction output is what cannot be used for consumption and non-reconstruction investment, and what is here referred to as "total losses."



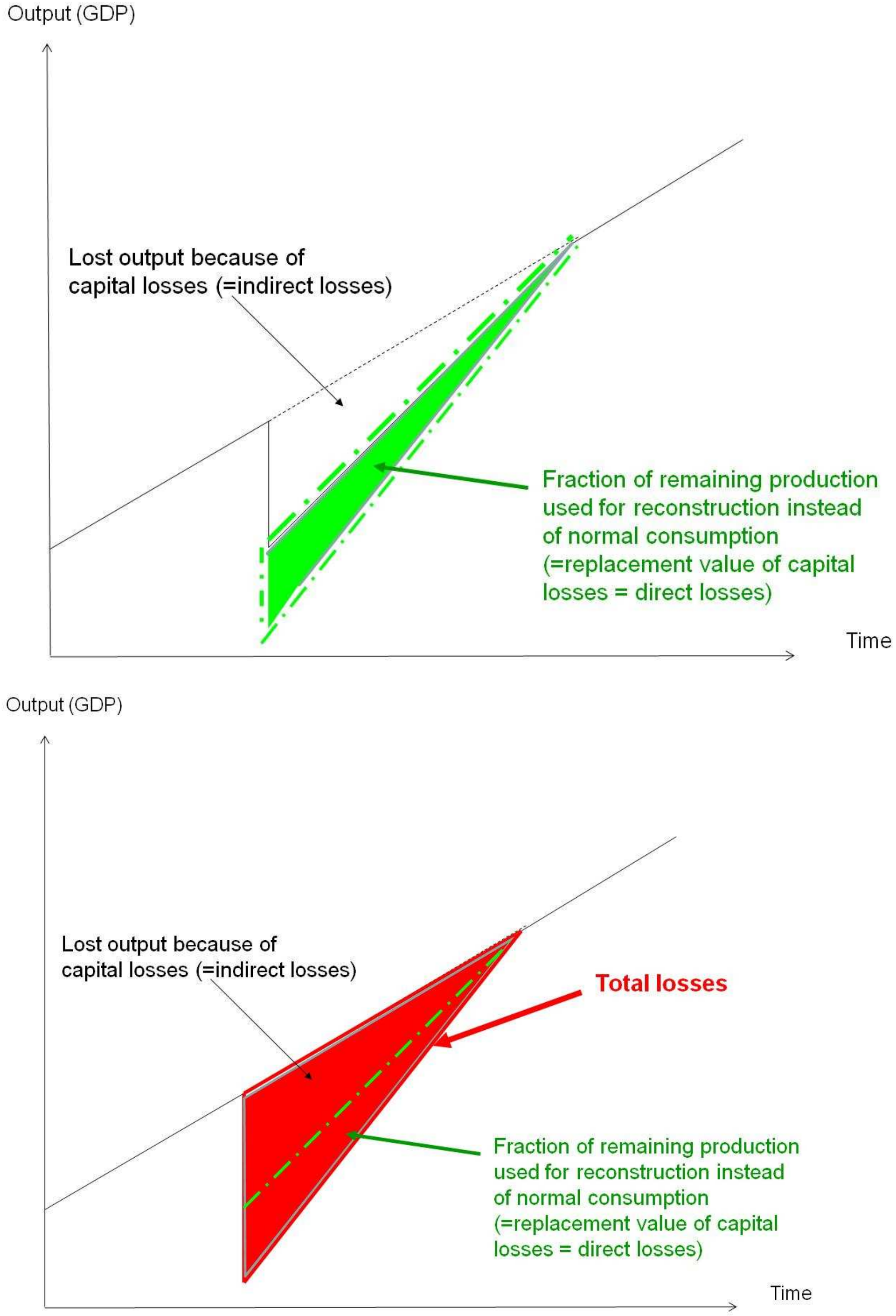
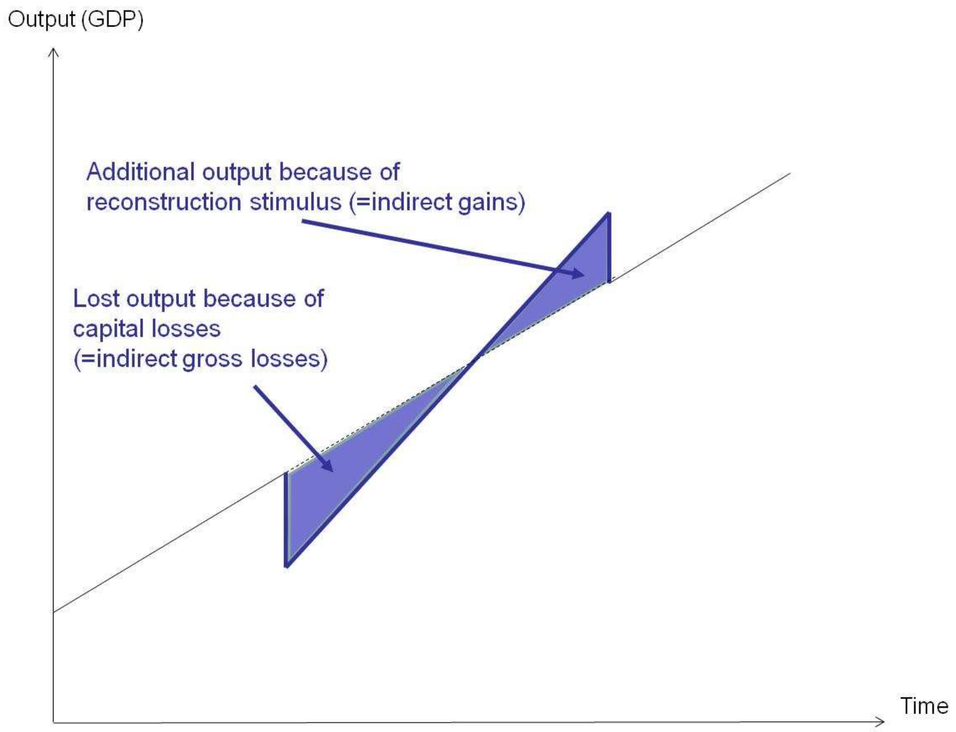


Figure 1: Direct losses, indirect losses, and "total" losses, i.e. consumption losses. This figure assumes that there is no flexibility in the production process.

In this framework, total costs is the sum of the indirect cost (i.e., the reduction of the total value added by the economy due to the disaster), and the direct cost (i.e., the portion of the remaining value-added that has to be dedicated to reconstruction instead of normal consumption). Capital and output losses can therefore be simply added to estimate consumption losses.

Of course, Fig. 1 shows a simplified situation in which production has no flexibility. In this case, reconstruction needs cannot be satisfied through increased production and it has to crowd out other consumptions and investments. Figure 2 depicts a different case, in which there is a limited flexibility in the production process: capital destruction leads to a reduction in output; but unaffected capital can increase its own production to compensate this reduction, for instance through an increase in work hours by workers at unaffected factories and businesses. In practice, there are gross indirect losses, and gross indirect gains (due to the stimulus effect of the reconstruction). But there is still a fraction of the remaining production that is used for reconstruction instead of normal consumption, even though this share is smaller than in absence of production flexibility.



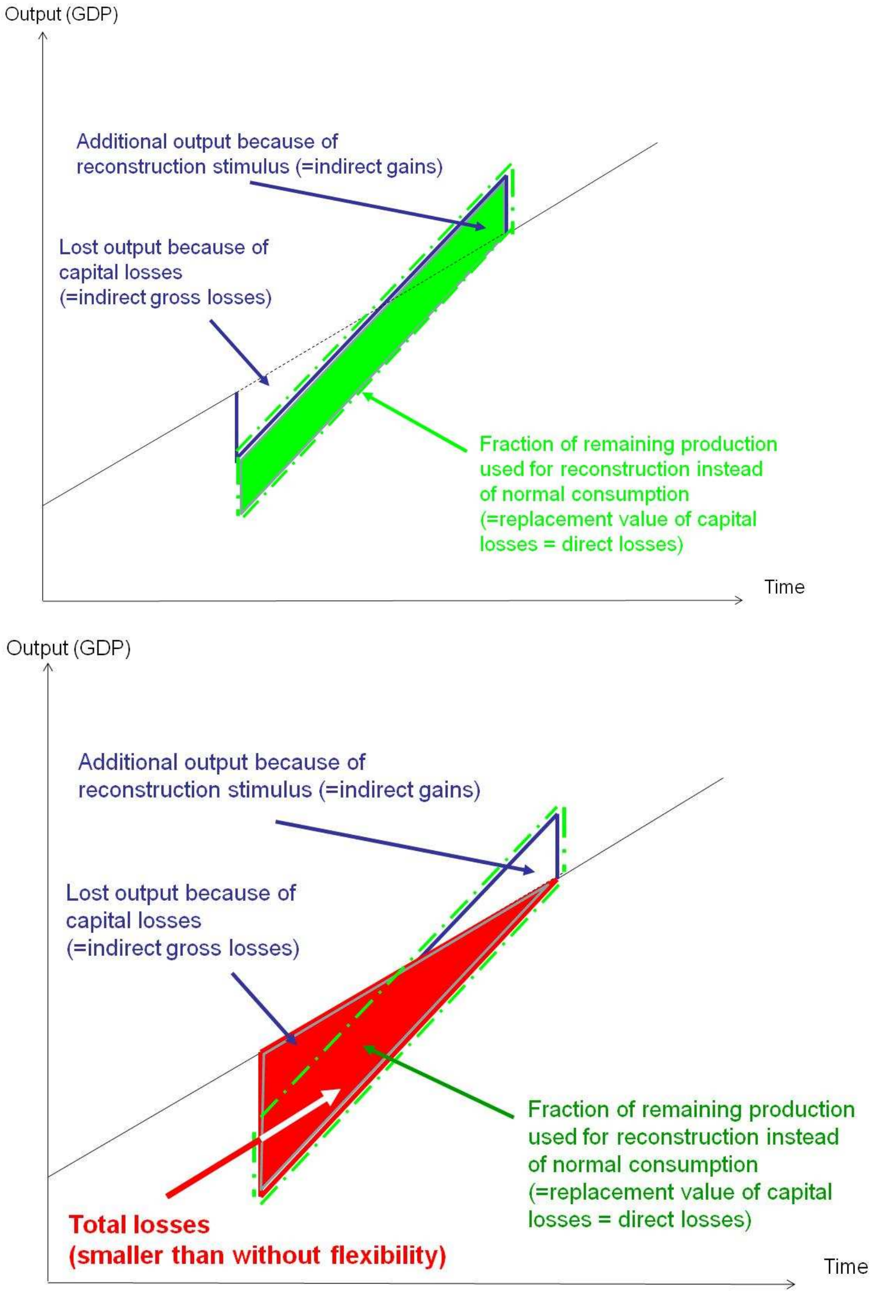


Figure 2: Direct losses, indirect losses, and “total” losses, i.e. consumption losses. This figure assumes that there is a limited flexibility in the production process.

In this situation also, the consumption loss is still the sum of direct (asset) and indirect (output) losses (Figure 2.c), making it necessary to estimate output losses. But output losses are not only the lost production from the affected capital, but also the output gains and losses from unaffected capital, in the rest of the economy. It makes the assessment of output losses more complicated, since it depends on complex economic mechanisms and trade-offs.

In practice, moreover, the reduction in consumption can be mitigated or amplified by (i) changes in prices; (ii) flexibility in the production process; (iii) changes in the saving-consumption trade-off for the remaining production and, (iv) the fact that the rebuilt capital will be more recent than before the disaster, with potential benefits (Hallegatte and Dumas, 2009). The following section will describe methodologies to assess output losses, and highlight the most important processes to take into account.

2.2 Main processes and methodological approaches

If output losses represent an important component of total losses, it becomes essential to develop methodologies to assess them. To do so, we propose to start by assessing the lost output from the directly affected capital. In a second subsection, we investigate the systemic impacts of disasters, including the effect on the capital that is not directly affected by the disaster, and we will see that these mechanisms lead to several open research questions.

2.2.1 From asset losses to output losses

The first step in an assessment of output losses is to estimate how much output is lost because of direct asset losses. Economic theory states that, at the economic equilibrium and under certain conditions, the value of an asset is its expected future production, and this equality has been widely used to assess disaster output losses. Assuming this equality is always verified, the output loss caused by capital loss is simply equal to the value of the damages, capital losses and output losses are simply equal, and the sum of asset and output losses is the double of asset losses.

The assumption that output losses are equal to capital losses is however based on strong assumptions, which are not always verified.

In estimates of disaster consequences, what is referred to as “asset loss” is the replacement value of the capital. To have the equality of asset loss and output loss, a double equality needs to be verified: replacement value has to be equal to market value; and market value has to be equal to the net present value of expected output. In an optimal economy at equilibrium, these two equalities are valid: First, the market value of an asset is by definition the net value of its output; Second, if market value were higher (lower) than replacement value, then investors would increase (decrease) the amount of capital to restore the equilibrium.

Therefore, in theory, there is no difference between capital losses and the reduction in output from this capital. But the assumption of the economics being optimal and at equilibrium is questionable.

First, for the replacement value and the market value to be equal, the economy needs to be at its optimum, i.e. the amount of capital is such that its return is equal to the (unique) interest rate.

This is unlikely for the capital that is affected by natural disasters, especially as infrastructure and public assets are heavily affected. Since these assets are not exchanged on markets, they have no market prices. Moreover, they are not financed by private investors, but decided about through a political process taking into account multiple criteria (e.g., land-use planning objectives), and there is no reason for their purely-financial return to be equal to the (private) interest rate. Practically, some assets may have an output value lower than their replacement value (e.g., a secondary road that is redundant and does not provide a significant gain of time or distance), while some may have an output value much larger than their replacement value (e.g., a bridge that cannot be closed without large consequences for users).

Second, for market values to be equal to net present value of expected output, expectations have to be unbiased and markets need to be perfect. This is not always the case especially in sectors affected by disasters, where expectations can be heavily biased (e.g., in housing market).

Also, output losses are most of the time estimated from a social point-of-view. The equality between market value (for the owner) and expected output (for the society) is valid only in absence of externalities. Some assets that are destroyed by disasters may exhibit positive externality. It means that their value to the society is larger than the value of the owner's expected output. Public goods have this characteristic, among which most infrastructures.

An example is provided by the San Francisco Oakland Bay Bridge, which is essential to the economic activity in San Francisco and had to be closed for one month after the Loma Prieta earthquake in 1989. Its replacement value has no reason to be equal to the loss in activity caused by the bridge closure, because the bridge production is not sold on a market, the bridge has no market value, and the social return on capital of the bridge is unlikely to exhibit decreasing returns and is likely to be much higher than the interest rate. Another example is the health care system in New Orleans. Beyond the immediate economic value of the service it provided, a functioning health care is necessary for a region to attract workers. After Katrina landfall on the city, the absence of health care services made it more difficult to reconstruct, and the cost for the region was much larger than the economic direct value of this service.

2.2.2 Different perspectives lead to different methodology to assess indirect costs

Different methodologies are used to assess indirect costs. They are the result of different perspective in investigating the issue. First, differences may arise in the hypothesis in the representation of economics of natural disasters. Some prefer representing economics of natural disasters as a shock in an economy that is normally at equilibrium, referring to price mechanism to adjust. This leads to either theoretical adjustment or to General Computable Equilibrium approach. Some consider that heterogeneity of production function cannot lead to an adequate representation and focus on consumer surplus change. This is the case of some bioeconomic or hydrological-economic model such as Holden and Shiferaw (2004) and Brooker (1995) on drought which investigates the welfare effect of drought. These disparities in methodology coexist in economics and thus will coexist in natural disasters cost assessment. The FloodSite project provides a review on these aspects.

Second, certain hazard communities are used to rely on vulnerability assessment to conduct costs assessment. These analyses are mainly used to discriminate between options to mitigate the risks, not used for cost assessment itself. This is true across hazard communities such as CEPRI(2008) for floods, or New Zealand Climate Change Office (2003) on coastal hazard.

Thirdly, methodology is sometimes directly dependent of the scale and area of studies. This can be for different reason: purpose of the study, data availability, particular topography, or capacity to compare with past event. This leads to conclusive attempt of combining different approaches such as Chatterton et al. (2010) and Penning-Rowsell et al. (2002).

2.2.3 The systemic impact of natural disasters and open research questions

The equality between output losses and asset losses is questionable for any economic shock, small or large. The most important issues appear when considering very large shocks, or systemic events, which are the events that perturb the functioning of the entire economic system and affect relative prices. In this case, output losses may be damped or amplified by several mechanisms.

Changes in prices

Fig. 1 and 2 show output in real terms, i.e. with no monetary effects. But output losses can be estimated assuming unchanged (pre-disaster) prices or taking into account the impact of the disaster on prices4. Both assumptions lead to the same result if the disaster has only a marginal impact on the economy, with little impact of prices, but can be very different in the opposite situation. In other terms, one can assume that if a house is destroyed, the family who owns the house will just have to rent another house at the pre-disaster price. But this assumption is unrealistic if the disaster causes more than a marginal shock. In post-disaster situations, indeed, a significant fraction of houses may be destroyed, leading to changes in the relative price structure. In this case, the price of alternative housing can be much higher than the pre-disaster price, as a consequence of the disaster-related scarcity in the housing market. Estimating the value of lost housing service should then be done using this higher cost instead of the pre-disaster one, which can lead to a significant increase in the assessed disaster cost. Unfortunately, it is difficult to predict ex ante the change in prices that would be caused by a disaster, making loss assessment more complicated.

[4] An alternative assumption is used in Computable General Equilibrium (CGE) Models, in which prices adjust instantaneously and optimally to reduce impacts. Such an adjustment appears inconsistent with what is observed in disaster aftermath (with little change in prices except in the construction sector). But price elasticity in CGE can be seen as an artificial way of modeling substitution, model prices being proxies for scarcity in each sector. The fact that real-world prices do not react like model prices does not mean that this “trick” is not useful to model substitution in scarcity situation.

The same reasoning is possible in all other sectors, including transportation, energy, water, health, etc. In extreme cases, reconstruction may even be impossible, at all prices. This is because markets are not at equilibrium in disaster aftermath (i.e., price is not such that demand equals production). The « If I can pay it, I can get it » assumption is not valid in post-disaster situations. In these situations, therefore, the value of lost production cannot always be estimated as the product of lost produced quantity and pre-disaster prices. Providing an unbiased estimate requires an assessment of the disaster impact on prices.

Often considered as resulting from unethical behavior from businesses, which are thought to benefit from the disaster, post-disaster price inflation can also have positive consequences. This inflation, indeed, helps attract qualified workers where they are most needed and creates an incentive for all workers to work longer hours, therefore compensating for damaged assets and accelerating reconstruction. It is likely, for instance, that higher prices after hurricane landfalls are useful to make roofers from neighboring unaffected regions move to the landfall region, therefore increasing the local production capacity and reducing the reconstruction duration. Demand surge, as a consequence, may also reduce the total economic cost of a disaster, even though it increases its burden on house owners.

The method used here proposes a different perspective on the role of prices in disasters than Computable General Equilibrium, that we suggest being nearer to post disaster conditions.

Length of the reconstruction phase

Importantly, there is a large difference between losing a home for one day (in this case the total loss is the reconstruction value, i.e. the direct loss) and losing a home for one year (in this case the total loss is the reconstruction value, i.e. the direct loss, plus the value of one year of housing services, i.e. the output loss). Of course, the longer the reconstruction period, the larger the total cost of the disaster.

The reconstruction phase, and the economic recovery pace, will ultimately determine the final cost of the natural disasters. The reconstruction pace is linked to the constraints to the reconstruction phase, which are of two types. First, they can be financial. This concerns situations in which households and businesses can simply not finance the reconstruction. This is of particular importance in countries with limited resources (Freeman et al., 2002 ; Mechler et al., 2006).

Constraints are also technical. Technical limits to the ability to increase production are obvious in the construction sector, which experience a dramatic increase in demand after the disaster. In spite of this demand, production does not follow, because there are strong constraints on reconstruction. Many households are able to pay for reconstruction, but cannot find workers and contractors to carry out the work. The same is true for businesses and factories. This explains why reconstruction often takes several years, even for limited damages (e.g., the 2004 hurricane season in Florida; see McCarty and Smith, 2005, Turner et al., 2008). Examples of constraint include the availability of equipment and qualified workers. For instance, the limited availability of glaziers increased the cost of reconstruction and lowered the reconstruction pace after the 2001 chemical explosion in Toulouse (France), despite glaziers coming from all the country to carry out the work.

Output gains and losses from the non-affected capital

Damages in crucial intermediate sectors may lead to negative “network effects” in the economy, leading to production losses even for businesses that are not directly affected by the disaster. Water, electricity, gas and transportation are the most critical sectors, and their production interruption has immediate consequences on the entire economic system. In past cases, it has been shown that the indirect consequences of utility services had larger consequences than direct asset losses, both on households (McCarty and Smith, 2005) and on business (e.g., Tierney, 1996). Of course, when capital cannot produce because of a lack of input (e.g., electricity, water), input substitution, production rescheduling, and longer work hours can compensate for a significant fraction of the losses (see Rose et al., 2007). These mechanisms can damp the output losses, and can especially reduce the crowding-out effects of reconstruction on normal consumption and investment (see Fig. 2). But their ability to do so is limited, especially when losses are large.

There are many sources of flexibility in the economic system. First, production capacity is not fully used in normal times, and idle production capacity can be mobilized in disaster aftermath to compensate for lost production from lost assets. Second, behaviors can change in disaster aftermath, and workers can increase their work hours in unaffected businesses to help society cope with disaster consequences (and sometimes benefit from increased prices). As a consequence, unaffected capital can often increase production to compensate for output loss from affected capital. After mild disasters, net output gains can even be observed, explained by the non-zero price elasticity of production, and by the under-optimality of the pre-disaster situation that leaves some room for increased production. In an economy that fully uses all resources and cannot increase its production over the short-term (whatever the price level), such a gain would be impossible. In a more realistic economy that does not use efficiently all resources (with under-employment, and imperfect allocation of capital), additional demand does not lead only to inflation, but also to increased output.

The stimulus effect of disasters

Disasters lead to a reduction of production capacity, but also to an increase in the demand for the reconstruction sector and goods. Thus, the reconstruction acts in theory as a stimulus. However, as any stimulus, its consequences depend on the pre-existing economic situation, or the phase of the business cycles. If the economy is in a phase of high growth, in which all resources are fully used, the net effect of a stimulus on the economy will be negative, for instance through diverted resources, production capacity scarcity, and accelerated inflation. If the pre-disaster economy is depressed, on the other hand, the stimulus effect can yield benefits to the economy by mobilizing idle capacities. This complex interplay between business cycles and natural disasters economics is analyzed in detail in Hallegatte and Ghil (2008), who support the counter-intuitive result that economies in recession are more resilient to the effect natural disasters. This result appears consistent with empirical evidence. For instance, the 1999 earthquake in Turkey caused destructions amounting to 1.5 to 3% of Turkey's GDP, but consequences on growth remained limited, probably because the economy had significant unused resources at that time (the Turkish GDP contracted by 7% in the year preceding the earthquake). In this case, therefore, the earthquake may have acted as a stimulus, and have increased economic activities in spite of its terrible human consequences. In 1992 also, when hurricane Andrew made landfall on south Florida, the economy was depressed and only 50% of the construction workers were employed (West and Lenze, 1994). The reconstruction needs had a stimulus effects on the construction sectors, which would have been impossible in a better economic situation.

The productivity effect

When a disaster occurs, it has been suggested that destructions can foster a more rapid turnover of capital, which could yield positive outcomes through the more rapid embodiment of new technologies. This effect, hereafter referred to as the "productivity effect", has been mentioned for instance by Albala-Bertrand (1993), Stewart and Fitzgerald (2001), Okuyama (2003) and Benson and Clay (2004). Indeed, when a natural disaster damages productive capital (e.g., production plants, houses, bridges), the destroyed capital can be replaced using the most recent technologies, which have higher productivities. Examples of such upgrading of capital are: (a) for households, the reconstruction of houses with better insulation technologies and better heating systems, allowing for energy conservation and savings; (b) for companies, the replacement of old production technologies by new ones, like the replacement of paper-based management files by computer-based systems; (c) for government and public agencies, the adaptation of public infrastructure to new needs, like the reconstruction of larger or smaller schools when demographic evolutions justify it. Capital losses can, therefore, be compensated by a higher productivity of the economy in the event aftermath, with associated welfare benefits that could compensate for the disaster direct consequences. This process, if present, could increase the pace of technical change and accelerate economic growth, and could therefore represent a positive consequence of disasters.

As an empirical support for this idea, Albala-Bertrand (1993) examined the consequences of 28 natural disasters on 26 countries between 1960 and 1979 and found that, in most cases, GDP growth increases after a disaster and he attributed this observation, at least partly, to the replacement of the destroyed capital by more efficient one.

However, the productivity effect is probably not fully effective, for several reasons. First, when a disaster occurs, producers have to restore their production as soon as possible. This is especially true for small businesses, which cannot afford long production interruptions (see Kroll et al., 1991; Tierney, 1997), and in poor countries, in which people have no mean of subsistence while production is interrupted. Replacing the destroyed capital by the most recent type of capital implies in most cases to adapt company organization and worker training, which takes time. Producers have thus a strong incentive to replace the destroyed capital by the same capital, in order to restore production as quickly as possible, even at the price of a lower productivity. In extreme case, one may even imagine that reconstruction is carried out with lower productivity, to make reconstruction as fast as possible, with a negative impact on total productivity. Second, even when destructions are quite extensive, they are never complete. Some part of the capital can, in most cases, still be used, or repaired at lower costs than replacement cost. In such a situation, it is possible to save a part of the capital if, and only if, the production system is reconstructed identical to what it was before the disaster. This technological “inheritance” acts as a major constraint to prevent a reconstruction based on the most recent technologies and needs, especially in the infrastructure sector.

This effect is investigated in Hallegatte and Dumas (2008) using a model with embodied technical change. In this framework, disasters are found to influence the production level but cannot influence the economic growth rate, in the same way than the saving ratio in a Solow-like model. Depending on how reconstruction is carried out (with more or less improvement in technologies and capital), indeed, accounting for the productivity effect can either decrease or increase disaster costs, but is never able to turn disasters into positive events.

Poverty traps

It is crucial to also take into account the possibility that natural disasters increase poverty. In particular, because they destroy assets and wipe out savings, they can throw households into “poverty traps”, i.e. situation in which their productivity is reduced, making it impossible for them to rebuild their savings and assets. These micro-level poverty traps can also be created by health and social impacts of natural disasters: it has been shown that disasters can have long-lasting consequences on psychological health (Norris, 2005), and on children development (from reducing in schooling and diminished cognitive abilities; see for instance Santos, 2007; Alderman et al., 2006).

These poverty traps at the micro-level (i.e. the household level) could even lead to macro-level poverty traps, in which entire regions could be stuck. Such poverty traps could be explained by the amplifying feedback reproduced in Fig. 3: poor regions have a limited capacity to rebuild after disasters; if they are regularly affected by disasters, they do not have enough time to rebuild between two events, and they end up into a state of permanent reconstruction, with all resources devoted to repairs instead of addition of new infrastructure and equipments; this obstacle to capital accumulation and infrastructure development lead to a permanent disaster-related under-development. This effect has been analyzed by Hallegatte et al. (2007) with a reduced-form model that shows that the average GDP impact of natural disasters can be either close to zero if reconstruction capacity is large enough, or very large if reconstruction capacity is too limited (which may be the case in less developed countries).

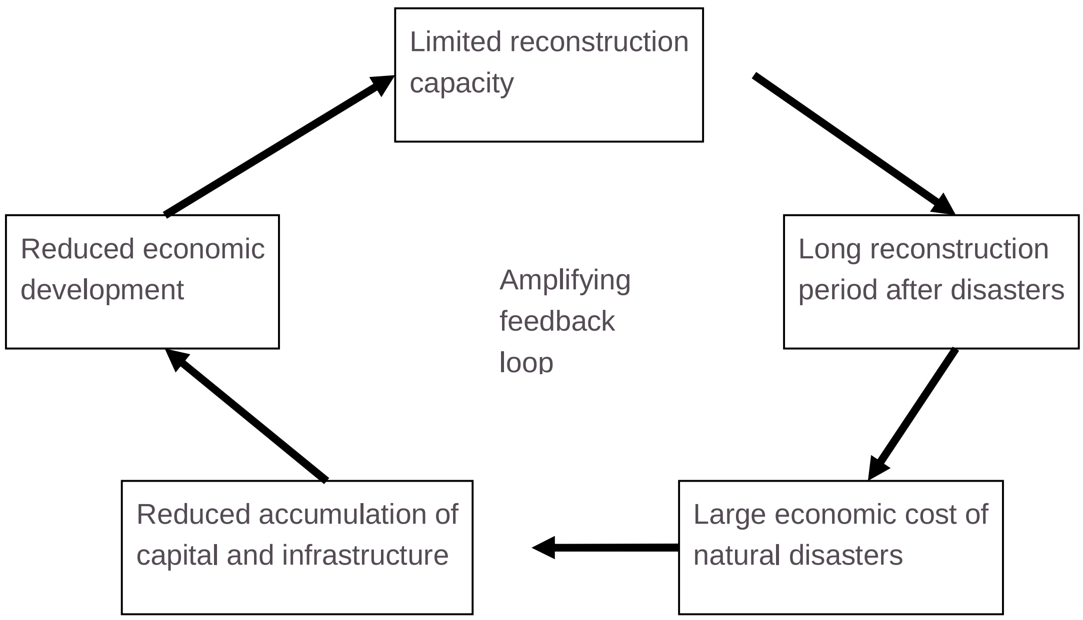


Figure 3: Amplifying feedback loop that illustrates how natural disasters could become responsible for macro-level poverty traps.

This type of feedback can be amplified by other long term mechanisms, like changes in risk perception that reduces investments in the affected regions or reduced services that make qualified workers leave the regions. Because of these mechanisms, the consequences of a disaster can last much longer than what is considered the recovery and reconstruction period.

2.3 Identification and description of the cost assessment methods applied to valuate the indirect impacts

Higher-order losses are sometimes measured using firm- or household-level surveys (e.g., Kroll et al., 1991; Tierney, 1997; and Boarnet, 1998; Smith and McCarty, 2006). More frequently, they are estimated using economic models, including (i) microeconomic models at the household level (e.g., Dercon, 2004); (ii) econometrics models at the local level (e.g., Strobl, 2008) or the national level (Albala-Bertrand, 1993; Skidmore and Toya; 2002; Noy and Nualsri 2007); (iii) input-output (IO) models at the regional or national level (e.g., Gordon et al., 1998; Okuyama and Chang, 2004; Hallegatte, 2008); (iv) Computable General Equilibrium (CGE) models at the regional or national level (e.g., Rose et al., 1997; Rose and Liao, 2005, 2007; Tsuchiya et al., 2007); or (v) network-production system model, even though this line of research has not been operationalized yet (Haimes and Jiang, 2001; Henriet and Hallegatte, 2008).

The assessment of these indirect losses is particularly difficult at the subnational level. A first difficulty lies in the limited availability of economic data at local level, as most information is at national level. This limitation makes econometric approaches difficult to implement. A second problem arises from the relationship between the affected area and the rest of the economy. Local losses can be compensated by various fluxes from the rest of the world. These fluxes include flux of goods if local production is insufficient; flux of workers for reconstruction (TBC); flux of capital if reconstruction needs exceed available resources, especially from government support and foreign aid (e.g., Stromberg, 2007). Interactions with the rest of the world also include ripple-effect, like the increase in oil price after hurricane Katrina hit the Golf Coast, which had nationwide and international negative consequences (TBC). Also, loss of market share by local business can be counted as losses, but they may correspond to gain for other businesses in another region.

2.3.1 Data collection on past events

A first line of assessment consists of data collection on past events. This approach considers a single event in a single location. For instance, using firm-level surveys, Kroll et al. (1991), Tierney (1997), and Boarnet (1998) investigate the consequences of lifeline and transportation interruption of firm activity and survival for the Loma Prieta earthquake in 1989 and the Northridge earthquake in 1994. They found that the consequences of infrastructure-related indirect impacts are often larger than the direct impact on firm. West and Lenze (1994) summarize the impact of hurricane Andrew on Florida, including job market consequences. The Bureau of Labor Statistics (2006) of the US also provides a detailed analysis of the large labor market consequences of hurricane Katrina. Using household survey in three counties and 16 cities after the 2004 hurricane landfalls in Florida, Smith and McCarty (2006) show that households are more often forced to move outside the affected area by infrastructure issues than by structural damages to their home.

Data collection on an event is the most commonly used methodology as it is quite simple to carry forward. It is often done using simple indicators such as for instance the number of days of closure for a tourist resort. This methodology seems to be used commonly for assessing mitigation measures, in particular with CBA method. Examples of this methodology and its results are proposed in the case of Alpine Hazards in the ConHaz, WP8 Report on the Cost of Alpine Hazards, by Thieken and Pfurtscheller.

2.3.2 Econometric approaches (statistical analysis)

Econometric approaches are based on statistics and do not investigate a single event. On the opposite they focus on series of events and investigate the “mean” indirect cost of these events, like the average impact on long term economic growth.

Econometrics analyses at national scale have reached different conclusions on the impact of disasters on growth. Alabala-Bertrand (1993) and Skidmore and Toya (2002) suggest that natural disasters have a positive influence on long-term economic growth, probably thanks to both the stimulus effect of reconstruction and the productivity effect (also labelled “Schumpeterian creative destruction effect” or productivity effect, described earlier in Section 4.b.). Others, like Noy and Nualsri (2007), Noy (2009), Hochrainer (2009), Jaramillo (2009), and Raddatz (2009), suggest exactly the opposite conclusion, i.e. that the overall impact on growth is negative. As suggested by Cavallo and Noy (2010) and Loayza et al. (2009), the difference between both conclusions may arise from different impacts from small and large disasters, the latter having a negative impact on growth while the former enhance growth.

There are also examples of local-scale econometric approaches. For instance, Strobl (2008) investigates the impact of hurricane landfall on county-level economic growth in the US. This analysis shows that a county that is stuck by at least one hurricane over a year sees its economic growth reduced on average by 0.79 percentage point, and increased by only 0.22 percentage point the following year. On Vietnam, Noy and Vu (2009) investigate the impact of disasters on economic growth at the province level, and found that lethal disasters decrease economic production while costly disasters increase short-term growth. GDP is not the only relevant indicator of disaster economic consequences, and Rodriguez-Oreggia et al. (2009) focus instead on poverty and the World Bank’s Human Development Index at the municipality level in Mexico. They show that municipalities affected by disasters see an increase in poverty by 1.5 to 3.6 percentage point. Looking at different economic variables, Hallstrom and Smith (2005) assess the impact of hurricane risk perception on housing values in Florida, and find that hurricane risks reduces property values by 19 percent.

Econometric approaches can use either real statistical data or synthetic data. Synthetic data are created by combining real data with additional information, like an assumption on the shape of the distribution function or a model based on physical mechanism. This approach is useful because large-scale events do not occur often enough to be able to derive precise historical statistics (in particular since the documentation of events has started in the second half of the 20th century with a steady improvement in methodology). Using synthetic data change the uncertainty associated with the results (as assumptions are made on the distribution).

It has to be noted that econometric analysis are not exclusive of other methodologies. Indeed, data collection on past events can be followed be econometric investigation if enough past events are documented , while model based approach can be calibrated using econometric results. Thus, this section refers in fact to methodology based on the use of econometrics as a tool of statistical analysis.

2.3.3 Model-based approaches designed for cost assessment: input-output models, computable general equilibrium models, and hybrid models (intermediary between CGE and IO)

The “adaptability” and “flexibility” of the production system and its ability to compensate for unavailable inputs is largely unknown and largely depend on the considered timescale. Over the very short term, the production system is largely fixed, and the lack of one input can make it impossible to produce. Moreover, over short timescales, local production capacity is likely to be highly constrained by existing capacities, equipments and infrastructure. Only imports from outside the affected region and postponement of some non-urgent tasks (e.g., maintenance) can create a limited flexibility over the short-term. This is what is represented in economic Input-Output model (e.g., Rose and Miernyk, 1989; Haimes and Jiang, 2001; Okuyama, 2004; Rose and Liao, 2005 ; Haimes et al., 2005), in which producing one unit of output requires a fixed amount of all input categories.

Over the longer term and the entire reconstruction period, which can stretch over years for large-scale events, the flexibility is much higher: relative prices change, incentivizing production in scarce sectors; equipments and qualified workers move into the affected region, accelerating reconstruction and replacing lost capacities; and different technologies and production strategies can be implemented to cope with long-lasting scarcities. The production system organization can also be adjusted to the new situation: one supplier that cannot produce or cannot deliver its production (because of transportation issues, for instance) can be replaced by another suppliers; new clients can be found to replace bankrupt ones; slightly different processes can be introduced to reduce the need for scarce inputs (e.g., oil-running backup generator can be installed if electricity availability remains problematic). These types of substitution are represented in Calculable General Equilibrium models (e.g., Morridge et al., 2003; Rose et al., 2007), in which the scarcity of one input translates into higher price, and reduced consumption of this input, compensated by larger consumption of other inputs.
IO models are often considered too pessimistic, since they assume that prices are fixed and that no substitution can take place in the production system. CGE models are on the opposite considered as too optimistic, since they assume that markets function perfectly (even in post-disaster situations), and that optimal prices balance production and demand and act as signals to incentivize production of the most needed goods and services.

The reality probably lies somewhere in between these two extremes, prompting the work on intermediate models. These intermediate models are either IO models with flexibility like in Hallegatte (2008), CGE models with reduced substitution elasticity like in Rose et al. (2007), or I/O-

CGE hybrid with bottom characteristics such as Hottidge et al. (2007) TERM Model for analysing Australian drought 2000-2003.

These models emphasize the importance of infrastructure (see, e.g., Haimes and Jiang, 2001). For instance, transportation is crucial and losses in this sector have large ripple effects on the rest of the economy, as shown by Gordon et al. (1998). In their analysis of the Northridge earthquake, they used the Southern California Planning Model (SCPM) and found that a substantial share of business interruption were due to off-site problems, such as disruptions in the transportation system that restricted the movement of goods and employees. Tsuchiya et al. (2007) reached the same conclusion in simulated Tokai-Tonankai earthquakes in Japan, applying a spatial CGE.

The water and electricity sectors also play a significant role. Rose et al. (2007) analyzed the impact of a two-week total blackout due to a potential terrorist attack in Los Angeles, i.e. an approximate loss of production worth $250 million, and finds that the total cost would be about $13 billion, decreasing to $2.8 billion if extensive production rescheduling is possible at low cost. Rose and Liao (2005) and Rose et al. (2007) model these effects, using a general equilibrium framework where adaptation capacity is taken into account using elasticities of substitution. They show that indirect effects are potentially large and that adaptation mechanisms can be very efficient in reducing these indirect losses (by up to 86% in their case study on a terrorist attack on the electricity power grid serving the Los Angeles County).

For the landfall of Katrina on New Orleans, the availability of a large amount of data allowed many modelling analyses. Hallegatte (2008), for instance, estimated using a regional input-output model that indirect economic losses in Louisiana after Katrina amounted to $42 billion compared to $107 billion of direct economic losses. More generally, this analysis concludes that regional indirect losses increase nonlinearly with direct losses, suggesting the existence of threshold in the coping capacity of economic systems. In this analysis of Louisiana, indirect losses remain negligible (or even negative) for direct losses below $50 billion, and then increase nonlinearly to reach $200 billion for direct losses of the same amount (see Fig. 4). Also, indirect losses decrease rapidly if it is possible to “import” reconstruction means (workers, equipment, finance) from outside the affected region. This result highlights the importance of taking into account interregional interactions.

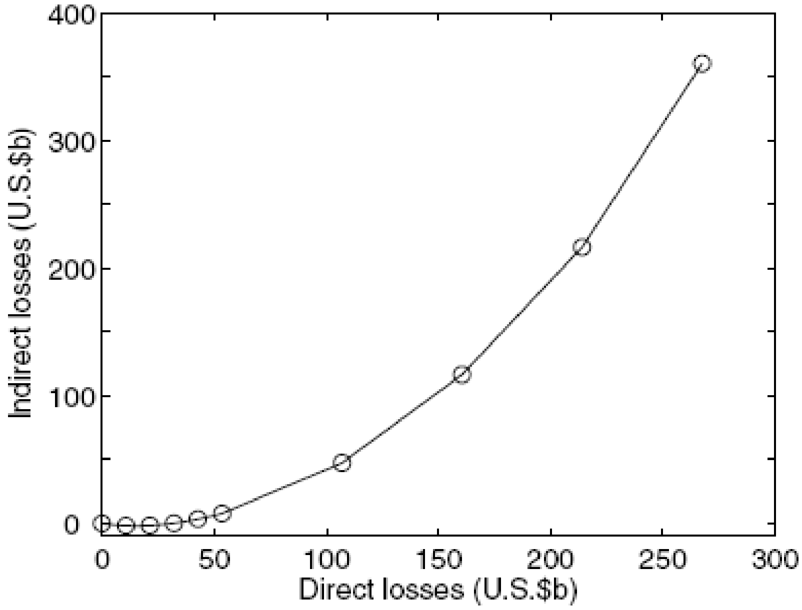


Figure 4: The direct losses – indirect (output) losses as a function of direct (asset) losses, in Louisiana for Katrina-like disasters. (source: Hallegatte, 2008)

This result highlights the importance of taking into account interregional interactions. This result is moreover reinforced by Okuyama (2004), who applies a Miyazawa's extension to the conventional input-output framework and the sequential interindustry model (SIM), introduced by Romanoff and Levine (1977), to assess the regional indirect cost of the Great Hanshin Earthquake in the Kinki region in Japan and the interregional impacts. He finds that most of the cost arises from income losses in the rest of Japan, due to reduced export to the Kinki region, showing that impacts outside the directly affected region cannot be disregarded.

2.3.4 Other model-based approaches: idealized models, hybrid physical-economic models, public finance coping capacity

Idealized models are theories or abstraction of empirics aimed at emphasizing mechanisms in place in economics of natural disasters. Even though their aim is not directly to assess the costs of extreme events, they help identify important mechanisms and investigate their role (e.g., Hallegatte and Dumas, 2008 for the role of endogenous technical change; Hallegatte and Ghil, 2008, for the interaction with business cycles). This literature reaching far out the risk community provides a scoping for models used for cost assessment.

In some hazards community, important example being given in the drought literature, the physical impacts and economic impacts are so linked that hybrid models combine physical aspects and economics. This is the case in the hydrological – economic model in Booker (1995) and the Biophysical-agroeconomic model in Holden and Shiferaw (2004). This methodology of cost assessment is probably not easily replicable outside the academic community but once again they provide an important scoping aspect in underlining mechanism, in this case outside the economic boundaries.

Another approach is the cost assessment based on the impact of natural disasters on public finances. It aims at assessing indirect costs in terms of capacity for government to cope with large expenses due to disasters and their subsequent abilities to deliver basic services while facing regular natural disasters. It implicitly considers impact on public finance and its capacity to overcome these challenges as a proxy for indirect costs, or as its main share. Example of this is the IIASA CATSIM model developed in Mechler et al. (2006) and applied to Honduras.

2.4 Data for cost-assessing the indirect impacts

2.4.1 Available data on the economic cost of disasters

The emergency Events Database (EM-DAT) maintained by the Center for Research on the Epidemiology of Disasters (CRED) at the Catholic University of Louvain, Belgium (http://www.emdat.be) is an important source of publicly available data on natural disasters. This database is compiled from diverse sources such as UN agencies, NGOs, insurance companies, research institutions and press agencies.
EMDAT defines a disaster as a natural situation or event which overwhelms local capacity and/or necessitates a request for exteneal assistance. For a disaster to be listed in the EMDAT database, at least one of the following criteria should be met:

- 10 or more people are reported killed
- 100 people are reported affected
- a state of emergency is declared
- a call for international assistance is issued

Disasters can be hydro-meteorological, including floods, wave surges, storms, droughts, landslides and avalanches; geophysical, including earthquakes, tsunamis and volcanic eruptions; and biological, covering epidemics and insect infestations (these are much more infrequent in this database).
The amount of damage reported in the database consists only of direct damages (e.g., damage to infrastructure, crops, and housing). The data report the number of people killed, the number of people affected, and the dollar amount of direct damages in each disaster. An alternative but similar source that is less extensive, and only parts of which are publicly available, is the Munich Re dataset.

Reinsurance companies surveys are also an extensive source of data but two main issues are met:

- the data are not publicly available, or only in a really aggregated fashion
- reinsurance companies are collecting data based on the losses insured, so biased towards countries in which insurance is developed and/or goods insured reporting a high value

2.4.2 Data needs for econometric analysis

For econometric analysis, long time series with sufficient numbers of events are required to have an adequate sample. Three main problems are met. First, a long time series is needed to ensure an unbiased estimation. Collection of data on natural disasters started to be precise and of large scope in the 90s. Earlier data collection is concerning mainly large events, and data are less precise. Second, large natural disasters are, hopefully, scarce. This does not allow for a large sample necessary for econometric analysis.
Third, the socio-economic baseline may be an important difficulty to distinguish effects of natural disasters from effects due to socio economic evolution. For instance, effects of natural disasters on economic growth may be difficult to disentangle from macroeconomic shocks, change in population, trends in urbanization, development of utilities networks etc.

2.4.3 Data needs for model-based approaches

Model-based approaches require large set of data (e.g., input-output tables) on the affected economy, and detailed data on which sectors are affected by the disaster. At regional scale, it is particularly rare to have IO tables (e.g., in the US, the BAE provides data at the state level), and table reconstruction using simple rules is sometimes necessary (see, e.g., Flegg et al., 1995; Hallegatte, 2008; Flegg et Tohmo, 2010).

The indirect impacts of a disaster largely depend on direct losses, and data on direct losses are often broadly aggregated and rarely disaggregated by sector. Also, data are often based on insurance industry data, and focus therefore on insurable goods. Non-insurable goods, and especially infrastructures, are often absent of these estimates. Again, simple methods may be used to recreate this data, but these data reconstruction methods add an additional large source of uncertainty in the assessment. Examples of methods are:

Sector disaggregation can be carried out using the sector values added, assuming that each sector is affected proportionally: if a sector is twice as large (in terms of VA) than another, then it would have suffered from losses that are twice as large (Hallegatte, 2008).

If sector-scale data on real-event losses are not available, models can be used to assess direct losses. Examples of models are catastrophe models from risk modelling companies (e.g., RMS, EQECat, AirWorldwide). This method can be applied only for events and regions in which risk modelling is available, i.e. mainly rich countries (e.g., hurricanes in the U.S.).

Infrastructure losses can be estimated assuming that the ratio between insurable and non-insurable losses is the same for all events. Using cases in which this information is know (e.g., Katrina in New Orleans), infrastructure losses can be reconstructed for other events (see Hallegatte et al., 2010, on coastal floods in Copenhagen).

3. Analysis and Assessment of the cost-assessment methods

There are different ways and criteria to assess disaster cost estimation methodologies. Depending on the objectives, disaster, and context, different methods will be more appropriate, precise, or applicable. Moreover, there is sometimes a complementarity between methods5. This Section provided information about each methodology in terms of resources required and expectations on results. However, one should keep in mind that the appropriateness of each method depends on the context and on the resources that are available (e.g., in terms of skills, data, time, financial resources), and that there is no methodology that appears better than the others in all circumstances.

(i) Scope and purpose of the assessment

The scope of assessment relates to the purpose of the assessment. These assessments can be used to help decision to help discriminating between various options. The approach may also be systemic or considering only certain type of costs. The choice may also to have hybrid models that consider physical as well as economic impacts or to the contrary only economic impacts.

(ii) Scale

The study can be at the micro, meso or macro level. Different scales lead to different methodological choices. For instance, public finances matter only at the macro level and cannot be assessed at lower scales.

(iii) Data availability and quality needs

The data availability and quality is a strong determinant of the method that can be undertaken. Low data requirement, or methods in which data can be reconstructed, such as some I/O models, may be an important aspect when choosing a method.

(iv) Effort required

Depending on all the precedent criteria, the efforts allocated to cost assessment is a strong factor in the choice of the methodology. Precision and high quality assessment may indeed simply not be replicable often due to the efforts that are needed to lead it. The methodology is dependent of the time and efforts allocated to it for its good execution.

(v) Scientific or practice approach

Whether the approach and application is only scientific in a scientific or a practitioner context is important. From this, follows two related criteria: the expected precision of the methodology and the skills required.

[5] WP5 on drought propose such an analysis p34 of their report.

(vi) Expected precision

(vii) Skills required

(viii) Are the dynamics of risk considered?

This emphasizes the capacity of the methodology to overcome a purely static approach in favor of underlining mechanism and causality in economics of natural disaster. This is also why in this background document, it comes across that purely idealized model cannot be totally ignored.

	Data collection on past events	Econometric approaches	I/O Models, CGE, hybrid I/O CGE, and public finance model	Idealised models and physical/economic model
Scope	Certain costs	Certain costs	System approach	System approach
Purpose	Decision making	Decision making (scientific evaluation	Scientific evaluation (decision making)	Scoping approach
Scale	Micro	Macro/Micro/Meso (cannot be mixed, depends on data) Higher precision on micro	Meso/Macro	Macro
Data requirement	High	High and quality is important	Medium, quality variable	Low requirement
Data availability	Difficult	Really difficult (difficult to obtain)	Manageable	not problematic
Effort required	Low	Low	High	High
Expected precision	Low	Depends on dataset and scale (generally low)	High	Low (idealised)
Scientific or practice approach	practice	Practice (or scientific depending on skills)	Scientific (practice is smaller version)	Scientific
Skills required	Low	Low if basic study, higher if more precise	High	High
Dynamics of risks considered	no	no	yes	yes

4. Indirect costs assessments in the different hazards research community

Emphasis on indirect costs and preferred methodology to assess indirect costs is not similar in every hazard research communities. The ConHaz project investigates four hazards categories, namely floods, drought, coastal and alpine hazards, successively addressed in WP5 to 8.

These different hazards community have different views on indirect cost methodologies and on the definition of indirect costs, and thus on the methodology to assess them. These different views relate to different practices, maturity but also to different viewpoints. In this paper we have presented the case for considering indirect costs as the basis for the next generation of costs assessments that is to say working on trajectories and path of economic development, with natural hazards being a disruption of a baseline scenario. This goes against a static view of a disaster and the consideration of recovery and reconstruction as a return to the pre-disaster situation.

On the question of definition between direct and indirect costs, the various workshops run in ConHaz for the different hazards highlighted the fact that the distinction between cost categories is of little relevance outside of research, provided that double counting is avoided.6 What matters most for end users is their scope of action, meaning they are ready to assess the indirect costs on which they can act. In practice, in particular, the boundary between direct and indirect is really blurry and can be decided using different criteria (e.g. based on end users, on type of methodology, on normative definition etc.).

Second, the assessment of indirect costs remain difficult and non consensual. With current knowledge, the practical implementation of indirect-cost assessment lie mainly in the questions it poses, more than in the answers we are able to provide. Considering indirect costs and conducting an assessment – even rough and simple – of indirect costs may highlight opportunities for low-cost, risk-reducing and welfare-improving options and policies.

On the methodology used or preferred for different hazard communities, here is a brief summary by hazards based on WP5 to WP8 work. Precise information is available in these background papers.

4.1 Floods (from WP6 “Cost assessment of Floods”, authors : Christophe Viavattene and Colin Green)

The boundary between direct and indirect costs is blurry and depends on the definition of the analysis boundaries (in time and space). To go further in assessing costs of an event, what is of importance is to assess the shock and its potential impact on the economy. The impact on the economy relate to the trajectory and the impact of the flood event on it as well as elements such as proportionality of the damages to the economy and reconstruction duration.

The final cost of the event is the difference between the trajectories of development with or without the flood. Even though this is what ultimately matters, it is almost impossible to rely on models to assess the total cost, as models mainly concentrate on calculable aspects – at the ex-

[6] Based on particular on the minutes on the session on indirect costs from the WP7 Workshop hold in Ferrara in March 2011, chaired by Valentin Przyluski, minutes taken by Clemens Pfurtscheller Minutes available on demand.

pense of non-market impacts – and tend to capture the initial shock (i.e. the direct impacts) more than the difference in trajectories.

What is proposed in WP5 is more a process than a methodology per se. It particular, it relies on interactions with decision-makers and stakeholders. To assess the benefits of risk mitigation options, it proposes first to determine the baseline scenario and the importance of this baseline in assessing the different costs related to each option. Second, it suggests to define the relevant indicators. These indicators are 'best proxies of what matters the most,' and have to be defined with stakeholders. Present value of each option plotted over time and over different course of action can then be estimated, but it is not the only information used for decision-making. Critical consideration of each option is necessary, with a special emphasis on resilience capacity and sustainability.

4.2 Drought (from WP5 "Cost assessment of Droughts"; authors, Ivana Logar, Jeroen Van den Bergh)

Good practice to assess direct and indirect costs is Computable General Equilibrium because it takes all sectors and all markets of the economy into account. It gives an estimate of overall economy wide costs. As the largest share of the costs is supported by the agriculture sector, precise methodology of pricing direct (Ricardian hedonic pricing) or indirect (economic-physical hybrid model) costs can be used. The limits of working at equilibrium need to be taken into account, however.

Statistical approach through economic analysis of GDP or decline in production in drought years is not to be preferred, because of the role of other drivers and because the GDP decline is not an optimal indicator of the costs of drought.

4.3 Coastal Hazards (from WP7"Cost assessment of Coastal Hazards"; authors, Quentin Lequeux, Paolo Ciavola)

Two main methodologies can be used to assess indirect impacts in coastal hazards. First, econometric multivariate assessments can be done.
This method has the main advantage of being very flexible in the choice of parameters that can be taken into account to valuate damages due to coastal hazards. The methodology does not necessary require predetermined data sets, but rather the development of a set of available and independent variables that can be correlated with total damage costs.

Input-output models are good approaches to assess indirect impacts in the aftermath of natural disasters such as hurricanes, even though the method may present some limitations, especially due to lack of flexibility in economic systems. This can be corrected with hybrid or adaptive model, such as ARIO (Hallegatte, 2008).
Depending on the type of input-output model, efforts in data collection may be relatively high, as input-output tables often need to be adjusted to the spatial scale and the period of the hazard event. Computable general equilibrium is able to deal with more flexibility in economic processes. Possible applications of such a method for the case of indirect costs of coastal storms could be further investigated, and its relevance and significance in results evaluated. However, this latter method may require high efforts given its complexity.

4.4 Alpine Hazards (from WP8 "Cost Assessment of Alpine Hazards"; authors, Clemens Pfurtscheller, Annegret Thieken)

Existing loss databases are inadequate to reflect regional risks and actual losses due to Alpine hazards. The assessment of indirect losses is a very difficult task and depends on the scale of the analysis, so it can often be assessed only by models.

Kletzan et al. (2004) and Baur et al. (2003) analysed also macroeconomic impacts (indirect effects on a macro scale) by macroeconomic modelling and by detailed analysing of national balances, distribution, income and prices of timber, but also tourism decline.
At the moment no advanced approaches exist for calculating loss due to business interruption caused by Alpine hazards.
Measuring indirect economic effects lead to the key task of identifying and evaluating the drivers and critical elements of indirect economic loss in the local and regional economy
Indirect loss is necessarily attached to some form of interruption of business but strictly different from the business interruption (disruption of production caused by the direct physical impacts on production facilities). In fact, very few studies and assessments exist for the indirect effects for Alpine risks aside from macro-economic models and rough estimates.

Few studies have carried out analysis of indirect costs but based on empirical observation of important sector rather than on macroeconomic modelling.

For instance, in Austria, the Federal Ministry of Agriculture, Forestry, Environment and Water Management (2008) carried out a CBA which calculates the business interruption losses by estimating and interviewing companies and the affected municipalities.

Other studies have used market valuation techniques (incl. insurance values), for example tax deficits (Fuchs 2004 ; Rheinberger et al.2009) and decline of touristic income (Nöthiger 2003). Nöthiger, (2003) assesses income decline in touristic income triggered by the avalanche. A tool based on questionnaire data on overnight stays, duration of the hazard impacts, fatalities, and daily visitors in the affected municipalities calculates the decline of income (indirect effects) in the month the hazard occurred, in the following month and in the long run in the different sectors (hotels, shops, trade, cable cars, and others).

4.5 Cross hazard perspective on indirect costs: feedback to indirect cost methodology

An ambition of the ConHaz project has been to allow for discussion between the methodologies and the hazards papers. This has been used as a space for improvement in common understanding. This section brings forward some elements in this regard, both for the synthesis and the vision papers.

To start with, there are broad concerns about the adequate matching between costing methodology and end-users needs. Two aspects are important. First, costing methodologies are developed to support decision making. The limitations of the assessments should be assessed, understood and passed to end-users dealing with the results. Second, two directions are consistent with end users needs for future development of indirect cost methodology: marginal improvement of current methodologies and a complete shift in approach. Indirect costs particularly highlight these two different paths.

The counterfactual (or baseline) and the recovery paths has an overwhelming role in the final figure of indirect losses. But determine the counterfactual poses difficult issues. These questions ultimately will determine the importance given to resilience, as a research direction to improve costing methodology.

The role of CGE models in assessing indirect impacts is a contentious point that is not to be resolved in the near term. However, departing from methodological considerations, agreement can be reached on the importance of taking both production and consumption into account. One step forward is the consideration of ‘needs’ and ‘welfare’, which has been the approach of this paper.

Then, the question of the purpose of the costing exercise is really important. It is widely recognized that any assessment should start with a detailed definition of the purpose. However, it raises several questions about assessing indirect costs for small scale events. This last type of events is the most regular but the least assessed in terms of indirect costs. Main issues are the impact of the structure of the economy (in particular supplier and clients), and the role of networks (social networks and supply chains). The ratio of indirect costs on total costs is seen as important to investigate. The notion of absolute and relative assessments is also to be developed forward with regard also to the notion of partial vs. full equilibrium, and in relation with end users needs and assessment boundaries.

5. Recommendations and Knowledge Gaps

This background paper highlights the main difficulties in defining, measuring, and predicting the total cost of disasters. It focuses on indirect (or output) losses, considered as a major component of the total loss of population welfare. There are several methodologies to assess these indirect losses, but they are all based on questionable assumptions and modelling choices, and they can lead to very different results. The main conclusion is twofold.

First, it is impossible to define "the cost" of a disaster, as the relevant cost depends largely on the purpose of the assessment. The best definition and method obviously depend on whether the assessment is supposed to inform insurers, prevention measure cost-benefit analyses, or international aid providers. A first lesson from this article is that any disaster cost assessment should start by stating clearly the purpose of the assessment and the cost definition that is used. Following this recommendation would avoid misleading use of assessments, and improper comparison and aggregation of results. Depending on the purpose of the assessment, the relevant definition of the indirect cost is different, and the most adequate methodology may also change.

Second, there are large uncertainties on indirect disaster costs, and these uncertainties arise both from insufficient data and inadequate methodologies. Considering the importance of unbiased estimates of disaster cost, for instance to assess the desirability of prevention measures, progress in this domain would be welcome and useful. To do so, much more research should be devoted to this underworked problem. Four main issues for future research are suggested:

First, the understanding of the economic response to external shocks, i.e. how the economic system can react and adapt in the recovery and reconstruction phase. This research would in particular include a better understanding of how markets function outside equilibrium, and of how agent expectation are formed in situations of high uncertainty.

Second, the understanding of interactions between the economic intrinsic dynamics (e.g., business cycles) and external shocks (e.g., natural disasters). The coexistence of these two dynamics explains why it is so difficult to "extract" the effect of natural disasters from macroeconomic data series. A better understand of their interaction would allow for a better measurement of disaster cost and for a better understand of relevant processes.

Third, the role of networks has been highlighted in the literature but requires additional work: specific network-shaped economic sectors (e.g., electric system, water distribution, transportation) are especially important, but other sectors also involve network through the organization of supply-chains. It is crucial to understand how failure in one business or production unit translates into operational problems for its clients (because of rupture in production input) and its suppliers (because of the reduction in demand). Network structures may play a role in the vulnerability of the economic system (e.g., having fewer suppliers may increase the vulnerability of a business) and analysis at the sector-scale may reveal insufficient to understand it.

Lastly, financial aspects also play a role: households and company may delay (or give up) reconstruction because of insufficient financial resources, households may reduce final demand because of lost income and assets, company may go bankrupt even if their production capital is still partly operational. These problems are especially important in developing countries. In general, this research line should also touch upon the role of the insurance industry (and of its regulation) and its capacity to help fund reconstruction and reduce natural disaster indirect cost.

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