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## LETTER

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# A framework to investigate the economic growth impact of sea level rise

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## Abstract

This article reviews the channels through which sea level rise can affect economic growth, namely the loss of land, the loss of infrastructure and physical capital, the loss of social capital, the additional cost from extreme events and coastal floods, and the increased expenditure for coastal protection. It discusses how existing studies on the direct impact of sea level rise could be used to investigate the resulting consequences on economic growth, emphasizes research needs on this question, and discusses consequences on migration.

**Keywords:** sea level rise, economic growth, welfare

## 1. Introduction

Among the different impacts of climate change, sea level rise raises much concern, and is the topic of much research. This research, however, focuses mainly on direct physical impacts of sea level rise, i.e. on the assessment of risks for human lives, and of potential loss of land, buildings, capital and infrastructure. The broader impact of sea level rise on the economic system has received less attention, and it seems important to investigate the possibility that sea level rise impacts negatively on economic growth and represents an obstacle to development and poverty reduction (e.g. World Bank 2009).

This article provides background information on this problem. Its contribution is threefold. First, it proposes a framework to discuss the economic growth impact of sea level rise. Second, it reviews the channels through which sea level rise can affect economic growth, namely the loss of land, the loss of infrastructure and physical capital, the loss of social capital, the additional cost from extreme events and coastal floods, and the increased expenditure for coastal protection. Finally, it discusses how existing studies on the direct impact of sea level rise could be used to investigate the resulting consequences on economic growth, emphasizes research needs on this question, and discusses consequences on migration.

## 2. A framework for economic growth

When investigating the impact of sea level rise on economic growth, one needs first to be explicit about the definition of

economic growth. Classically, economic growth is defined as the growth in gross domestic product (GDP), which is commonly estimated by economic statistics agencies. The GDP is the sum of the value added by all economic activities in a country.

What is recorded as 'economic output'  $Y$ , or GDP, can be either a narrow economic production (only what is produced by economic actors) or have a broader definition including ecosystem services and other non-market production (e.g., Arrow *et al* 2004, Dasgupta 2009, World Bank 2006).

Classical growth theory (Solow 1956) assumes that GDP, often referred to as output and denoted  $Y$ , is produced from 'production factors.' These production factors are technology  $A$  (i.e. the technologies used for production), physical capital  $K$  (i.e., infrastructure, housing, and production equipment), and human capital  $L$  (i.e., the labour force). In expanded growth frameworks, the 'natural capital'  $E$  is an additional production factor. Natural capital is the quality of the environment and renewable and non-renewable assets. It is productive because it is used directly as a resource (e.g., oil, timber), because of ecosystem services (i.e., the services provided for free by ecosystems like food production, see for instance Turner *et al* (2003), Bateman *et al* (2011), Barbier *et al* (2008a)), and because the environment plays a role in market-goods production (soil quality for agriculture, etc).

Other frameworks also introduce the 'social capital'  $S$  (including the quality of institutions and social norms) as

another input. In that case, output depends on technology and four categories of capital: the physical, human, natural and social capitals:  $Y = f(A, K, L, E, S)$ . In that case, output growth, i.e. GDP growth, is explained by growth in production factors  $K, L, E$  and  $S$ , and by improvement in technology  $A$ .

Progress in technology ( $A$ ) is explained by technological change, including changes in organization. In classical growth theory, productivity growth is exogenous and is considered as 'manna from heaven.' In *endogenous-growth models* (e.g., Arrow 1962, Lucas 1988, Mankiw *et al* 1992; Aghion and Howitt 1992), productivity growth depends on investments in education, research and development, on scale of output and on learning by doing. For instance, one can assume that productivity growth can be 'produced' thanks to investment in a 'stock of knowledge'.

Growth in labour  $L$  is explained by population growth, increase in labour force participation and improvements in health and education. Growth in  $K$  is explained by investment, and growth models assume that a share of output  $I_K$  is used to increase the stock of capital  $K$ , and that this stock is reduced by depreciation  $\delta_K$ :  $dK/dt = I_K - \delta_K K$ . Consumption  $C$  is given by production reduced by investments.

These theories of economic growth deal with long-term economic development, and do not discuss the shorter-term behaviour of economic variables. Indeed, the economic output  $Y$  described by growth theories can be defined as a potential output, i.e. the output if all production factors were fully and efficiently used. The real output depends on this potential output, and on how the economy is able to use production factors. In such a framework, one can write  $Y = ef(A, K, L, E, S)$ , where  $e$  is the efficiency of the economy. The high level of unemployment in developing and developed countries in 2011 results in a real output that is significantly lower than potential output, i.e. in a low  $e$ . The dichotomy between the long and the short term in economy has been criticized (e.g., Keynes 1937, Solow 1988), and many have called for a theory accounting for the short and long terms in a consistent framework.

Moreover, GDP as an indicator of economic performance has limits that are well known, and have been summarized in several recent reports (e.g., CMEPSP 2009). In particular, these reports suggest a shift from measuring economic production to measuring welfare. To do so, they recommend several changes. First, welfare depends more on income and consumption than on GDP; in our framework,  $C$  matters more than GDP, even though economic discussion mostly uses GDP. Second, the depletion of natural resources, i.e. a degradation of natural capital  $E$  in our framework, plays an important role. This depletion is measured in some extended growth frameworks. Third, one needs to take into account the concept of 'defensive' expenditures (Nordhaus and Tobin 1973). The cost associated with commuting is included in GDP, and even in consumption  $C$ , even though commuting does not yield welfare benefits but is only a requirement for other economic activities. And finally, many authors stress the importance of income and wealth distribution in measuring economic growth and welfare.

### 3. The impacts of sea level rise on economic growth drivers

Sea level rise will affect economic growth through many processes, including impacts on the four production capitals. In this section, we use the growth framework proposed in the previous section to organize these processes into five categories.

#### 3.1. Permanent losses of natural capital

First, sea level rise will lead to the definitive loss of land. Land is a natural resource and matters for economic production. In our framework, land is part of natural capital ' $E$ '; a loss of land is thus a loss of capital, with negative consequences on output. According to existing modelling studies, this loss will affect particularly agricultural production<sup>1</sup> (see Bosello *et al* 2007). Where land is scarce (or, equivalently, where all useable land is used for agriculture), the associated economic cost can be assessed by the land market value (or the value of farms, as in Mendelsohn *et al* (1994)).

As stated in Yohe (1991), the land market price cannot always be used directly to assess the economic cost of sea level rise. Indeed, land prices are often very high on the coastline, because of amenities (e.g., sea views) and of the proximity to port infrastructure. But if and where the coastline shifts and this land is lost, these amenities are transferred to land farther from the current coastline. So, sea level rise leads to a loss (from land loss) and a gain (from additional amenities in farther-inland locations). Only the net loss should be taken into account. Over the long-term, therefore, the economic loss from definitive land loss should not be calculated with the coastline land values, but using the farther-inland land values. These values being much lower than coastal ones, the economic cost of sea level rise is much more limited than could be derived from local land prices.

In addition to market economic impacts, sea level rise threatens some ecosystems and natural habitats. These potential losses can also be recorded as a decrease in natural capital  $E$ . These ecosystems provide important services like breeding zones for fish. If these services are included in economic output, these losses translate into an economic loss. If a narrow definition of GDP is used, then welfare losses exceed GDP losses.

When these services disappear, their value is lost or they have to be replaced by artificially provided services (e.g., protection from storm surge by a mangrove can be replaced by a dike; in that case, we substitute additional physical capital  $K$  for lost natural capital  $E$ ). In the narrow definition of economic growth, in which ecosystem services are not included, replacing ecosystem-based services by artificially provided services would increase GDP, and enhance economic growth. But the impact on welfare would be negative, because increased investment means reduced consumption.

<sup>1</sup> Sea level rise can also lead to soil salinization with large consequences on agriculture and drinking water availability.

### 3.2. Permanent loss of physical capital

Sea level rise can lead to the definitive loss of infrastructure and productive capital, i.e. to a loss of physical capital  $K$ . In some coastal areas, indeed, it is more rational to withdraw inland than to try to protect the area.

As discussed in Yohe *et al* (1996) and West *et al* (2001), we could imagine that this withdrawal will take place naturally, with the value of assets and investments regularly decreasing as the risk in the zone increases. At the time the zone should be evacuated, the assets would be at the end of their lifespan and would therefore have a zero value. In this case, the cost of withdrawal would be null. However, this is difficult to imagine for several reasons.

First, West *et al* (2001) discuss the role of anticipation and foresight, as only unrealistically perfect foresight would allow for this low-cost solution. Second, an urbanized zone is composed of many types of assets (housing, roads, etc) that have very different life spans, and it is difficult to imagine that all of these assets can arrive at full depreciation at the same time. Third, it is not possible to stop all maintenance and to use housings and roads that deteriorate over time and whose comfort and safety are compromised. We can clearly see that we cannot avoid abandoning assets that are still useable (with, therefore, a non-zero cost), even with a coordinated withdrawal organized by local authorities ('strategic withdrawal').

### 3.3. Permanent loss of social capital

Sea level rise might also affect social capital (Turner *et al* 1996). Indeed, a fraction of the population only would be affected by sea level rise and would require additional protection expenditures and support, at least in most countries. This could create political and social tensions since policies would have large redistributive effects: if large investments are made, the rest of the population can see them as inappropriate; if necessary investments are not made, the population at risk may feel unprotected by its government (Luisetti *et al* 2011). The resulting social and political tensions may be a strong obstacle to the smooth functioning of the institutions that is necessary to sustain balanced economic growth (e.g., Alesina *et al* 1996, Rodrik 1999).

### 3.4. Temporary floods and their impacts

The impact of sea level rise on economies and societies will not only go through the definitive inundation of some locations. In places that are not definitely inundated, the risk from coastal floods will increase (see, e.g., Hanson *et al* 2011). And this effect is reinforced by existing trends, with cities—and especially coastal cities—growing rapidly in response to trends in economic structure and life styles. Confronted with growing population, land scarcity and infrastructure gap, more marginal and high-risk land is urbanized every year.

If adequate measures are not implemented, this increase in risk could translate into larger economic losses for

coastal floods, including large losses in productive capital and infrastructure. Model-based case studies show, e.g., on Copenhagen (Hallegatte *et al* 2011), that the increase in risk could be very large where protections become insufficient. In our growth framework, this increase in risk would translate into additional losses of physical capital  $K$ . But disasters have other consequences.

In terms of human capital, disasters have a direct impact through injuries and loss of lives. But it has also been shown that disasters can have long-lasting consequences on child development (Santos 2007, Alderman *et al* 2006), with large consequences on labour productivity, health costs, growth and welfare. Moreover, disasters lead to significant migrations. After Katrina, for example, migrations outside the affected area, including permanent migrations (Landry *et al* 2007), have been observed. If disasters lead to out-migration, there will be consequences on economic growth; these consequences would be amplified if—as suggested by the Katrina case, see Zissimopoulos and Karoly (2007)—high-skilled, high-productivity workers are more able to migrate than the average population.

There are also consequences on social capital. First, risk perceptions influence the willingness to invest, and the trust in an economically successful future. Second, some disasters have led to political instability and conflicts in the past, especially when governmental support of affected population was ineffective (see Homer-Dixon (1999), and a discussion in Gleditsch and Urdal (2002)). These conflicts have negative consequences on long-term economic growth.

Finally, disasters can reduce natural capital, for instance when hurricane storm surges destroy mangroves, i.e. decrease natural capital  $E$ . These impacts reduce ecosystem services, with consequences on economic production  $Y$  and welfare.

If growth is understood more broadly and in welfare terms, then other impacts of natural disaster need to be included. Lindell and Prater (2003) and Tierney (2006) provide a summary of these impacts, including social impacts, health impacts and psychological impacts.

### 3.5. Increased coast protection expenditures and crowding-out of other investments

Sea level rise is a progressive and dynamic process, and a continuous adaptation process will take place to cope and react to it. This adaptation process will aim at (i) avoiding definitive loss of land and capital when their value is high; (ii) reducing coastal flood risks to acceptable levels in human settlements; (iii) retreating from areas that are not protected.

Several model-based analyses of adaptation in coastal areas have been proposed (Yohe 1991, Fankhauser 1994, Yohe *et al* 1996, West *et al* 2001, Yohe and Tol 2002, Yohe *et al* 2011). The 'cost' of sea level rise depends on assumptions on how adaptation can be carried out. With perfect adaptation (rational actors, no externalities, perfect foresight), the residual cost (after adaptation) remains small (e.g., Nicholls and Tol 2006).

The cost of adaptation is the sum of all investments (and maintenance costs) necessary to protect human settlements



located in at-risk areas. OECD (2008) estimates that the annualized costs for optimal levels of protection are typically relatively modest, frequently less than 0.1% of national GDP. However, adaptation costs may be high relative to the GDP of coastal areas, as it is not guaranteed that protection costs will be absorbed fully at the national level. It is useful to note that the assumptions on protection costs are particularly simple in these analyses that are based on broad estimates of hard protection building costs (e.g., Hoozemans *et al* 1993, Heberger *et al* 2009). In reality, protection costs for cities (e.g., New Orleans) can be much higher, because of the cost of land to build the protection, or because of the need for mobile protections to maintain port operations.

Darwin and Tol (2001) analyse the indirect impact of these investments in a static framework. In a growth framework, these expenditures can increase GDP by increasing demand, but they are clearly part of the defensive expenditures that should not be accounted in welfare-improving economic output.

#### 4. The impact on economic growth

Fankhauser and Tol (2005) and Lecocq and Shalizi (2007) investigate how climate change (including sea level rise) could influence growth and GDP. They identify two main mechanisms: a capital accumulation effect, if climate change leads to reduced investments or accelerated depreciation (in  $K, L, N$  or  $S$ ); and a savings effect, if climate change leads households and firms to change their behaviour. They show that, in models with endogenous technical change, these dynamic effects can even dominate the direct impact of climate change. This result is likely to remain valid when considering sea level rise only. This section discusses how direct sea level rise impacts can affect economic growth.

##### 4.1. Permanent capital losses and their impact on growth

In the simplest growth theory, i.e. a Solow–Swan economic growth framework with constant saving ratio, exogenous technical change and decreasing return on capital, a permanent loss in any of the four capitals does not reduce the long-term economic growth rate. Instead, the economy converges towards a pathway with the same growth rate, but with reduced GDP and consumption levels. In such a framework, indeed, the long-term economic growth rate is linked to technical progress only, which is assumed exogenous.

In the case of sea level rise, however, the process is slow and continuous over centuries, and this progressive reduction in capitals would translate into reduced long-term economic growth, even in a Solow–Swan framework.

In models with endogenous growth, productivity becomes endogenous. If sea level rise makes it necessary to invest more in coastal defences, the additional investment can crowd out other investments, and in particular investments in research & development. This crowding-out effect could then lead to reduced productivity growth and to reduced growth rates.

On the other hand, an increase in investment may also bring economic benefits in the form of higher activity and higher growth, if the economic situation is of insufficient demand, underproduction and unemployment (e.g., during an economic crisis). This stimulus effect can bring benefits, but one has to note that—in absence of sea level rise—the same stimulus could be obtained by investing in other useful infrastructure (housing, drinking water infrastructure, etc) instead of defensive investments.

##### 4.2. The growth consequences of temporary floods

Econometrics analyses at national scale have reached different conclusions on the impact of disasters on growth. Some suggest that natural disasters have a positive influence on long-term economic growth (e.g., Skidmore and Toya (2002)). Others, like Noy and Nualsri (2007), Noy (2009), Hochrainer (2009) and Raddatz (2007), suggest that the impact on growth is negative. As suggested by Cavallo and Noy (2011) and Loayza *et al* (2009), large disasters may have a negative impact on growth while smaller ones sometimes enhance growth through increased demand.

At local scale, Strobl (2011) investigates the impact of hurricane landfall on county-level growth in the US. He finds that economic growth is reduced on average by 0.79% point in counties affected by a hurricane landfall, and increased by only 0.22% point the following year.

But in the case of increasing disaster losses due to sea level rise, one can be concerned more about poverty traps than with small changes in growth rate. Disasters, indeed, destroy assets and wipe out savings, and can push households into ‘poverty traps’, i.e. situations where productivity is reduced, making it impossible for households to rebuild their savings and assets (Carter *et al* 2007, Dercon 2004, 2005, Lopez and Servén 2009, Van den Berg 2010).

These poverty traps at the micro level could lead to macro-level poverty traps, in which entire regions could be affected (Hallegatte *et al* 2007, Hallegatte and Dumas 2008). In our framework, this poverty traps can be interpreted as situations in which economic output becomes so low that populations cannot invest any more in the four capitals necessary to grow output.

Some have made the case that economic growth will reduce disaster losses in the future, by increasing resilience. However, the relationship between wealth and disaster vulnerability may not be monotonic. Growth and development can be risk reducing or risk increasing, depending on their structure and patterns. Hallegatte (2011) shows that—even assuming that economic agents behave in a perfectly rational way—natural disaster losses can grow faster than wealth in response to economic growth.

##### 4.3. Existing assessments

A few papers have investigated this question for sea level rise, but models remain too simple to investigate all mechanisms. Deke *et al* (2001) use a recursive calculable general equilibrium (CGE) model, in which the dynamics

is equivalent to a Solow–Swan growth model, to investigate the impact of the costs of coastal protection on economic growth and activity. They do not take into account land losses and additional flood risks, but the costs of coastal protection are subtracted from total investment in physical capital. Investment is thus distributed between unproductive coastal protection (defensive expenditures) and productive net investment. In their framework, protection costs reduce the capital stock, and hence economic output and future consumption. Their results suggest a very small impact of sea level rise on growth (with reduction in capital of less than 0.05% in all regions but India where capital is reduced by 1.3%), but they only consider a 13 cm sea level rise in 2100, which is extremely optimistic.

Using the same methodology, but accounting for all impacts of climate change (including sea level rise), Kemfert (2002) finds large GDP losses (up to 1.6% in 2050). This large loss arises from the reduction in investment and its impact on accumulation, not from direct climate change.

As also suggested by Fankhauser and Tol (2005) and Hallegatte *et al* (2007), these preliminary results support the idea that dynamic effects can dominate direct effects, and that current analyses focusing on direct losses from sea level rise need to be complemented with macro-economic analyses. In particular, it would be interesting to test whether conclusions on long-term impacts are dependent on which growth theory is used.

## 5. Conclusion and consequences on migrations

The main conclusion of this paper is that sizeable impacts of sea level rise on economic growth and welfare are possible, at least at the regional scale, even though it is difficult to quantify this effect with current knowledge. Indeed, little research has been done on this issue, compared with the efforts devoted to the assessment of sea level rise direct impacts. This paper suggests the need for more work on indirect impacts, investigating the various channels that are identified in this article.

This question is relevant in the context of this special issue, because the impact of sea level rise on economic growth will in turn affect demographics and migrations. Importantly, Black *et al* (2011) show that migrations have multiple interacting drivers, and that economic activity and income only represent one component of the migration decision, in addition to other social, cultural, demographic and politic drivers. There is thus no automatic causality between the economy and migrations.

Everything else being equal, however, lower growth can lead to crisis, unemployment and lower income, which are often followed by out-migration; see for instance, Harris and Todaro (1970) and Barro and Sala-i-Martin (1992) on income differences; and Fields (1975), and Greenwood (1997) for unemployment; and a review in Lilleor and van den Broeck (2011). Also, sea level rise may increase natural risks and thus income volatility (especially where safety nets and insurance systems are under-developed), leading to more temporary and definitive migrations (Rosenzweig and Stark 1989).

Migrations appear as an adaptation strategy to macro-economic crisis and economic opportunities. However, this adaptation mechanism leads to non-economic losses that need to be accounted for (loss of social networks that play a key welfare-improving role for the poorest; loss of the sense of place, loss of culture and traditions, etc). Also, this adaptation leads to a loss of human capital in the affected area, and can thus amplify the initial decrease in regional growth. It is especially the case if the first to out-migrate in response to reduced growth are those with highest skill and productivity, as is observed after natural disasters. For instance, the expansion of (coastal) mega-cities plays a major role in development and growth in Africa and Asia (e.g., Collier and Dollar 2001), and these cities are particularly vulnerable to sea level rise (Hanson *et al* 2011, Seto 2011). A reduction in migrations towards these places may impact negatively economic growth in the entire regions, and result in a slowing down of national economic growth.

Importantly, the consequences of sea level rise do not need to be very strong to lead to reduced growth and out-migration. If sea level rise creates a comparative disadvantage of some coastal areas compared to other locations (inland zones and coastal areas that are easier to protect), it can be enough to lead to significant regional or local economic losses (compensated by economic gains in other locations). These losses can then easily turn into reduced investment (loss of physical capital) and out-migration (loss of human capital), making the overall macro-economic and welfare impact much larger than can be expected from an analysis of direct losses from sea level rise.

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