AN EXAMINATION OF THE INTERNATIONAL TRADE IMPACTS OF CLIMATE CHANGE

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Summary

Over the next half century, international trade is projected to continue to increase in the world economy, outpacing the growth in gross domestic product (GDP). While economies will increasingly rely on trade, climate change will affect trade patterns and specialisation. Changes in the climate system, not least sea level rise and the increasing frequency of extreme events, will modify transport routes and infrastructures, thereby changing the access and possibilities for the international transport of goods and services. Other types of climate impacts, such as those on agriculture and labour productivity, will cause changes in production and specialisation, which will also affect trade.

The literature on trade has focused mostly on the trade consequences of climate change mitigation policies or on the effects on greenhouse gas emissions of trade policies. Dedicated analyses that look at the long-term impacts of climate change on international trade are still very scarce.

This paper provides an analysis of how climate change damages will affect international trade in the coming decades and how international trade can help limit the costs of climate change. It analyses the impacts of climate change on trade considering both direct effects on infrastructure and transport routes and indirect impacts resulting from changes in endowments and production. The paper also investigates trade as a means of reducing the negative economic consequences of climate change, i.e. as an instrument of adaptation to climate change. A qualitative analysis with a literature review is used to present the direct effects of climate change. The indirect impacts and trade as a means of adaptation are instead analysed with the OECD's ENV-Linkages model, a dynamic computable general equilibrium model with global coverage and sector-specific international trade flows.

The direct consequences of climate change on trade could become manifest in damages to trade from more frequent extreme weather events or rising sea levels. Supply, transport and distribution chains might become more vulnerable to disruptions due to climate change. Maritime shipping, which accounts for around 80% of global trade by volume, could experience negative consequences, for instance from more frequent port closures. At the same time there could also be positive impacts on maritime shipping by the potential further opening of Arctic shipping routes.

Indirect impacts on trade patterns primarily result from the regional and sectoral disparities in economic consequences that climate change will bring about. Model simulations show that climate change is projected to impact the production of goods and services through changes to the endowments and/or efficiency of factor of production of economies, i.e. land, labour, and capital.

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Both the direct and indirect effects of climate change on trade lead to changes to the comparative advantage of economies, and hence affect trade patterns. The results from the ENV-Linkages model simulations imply that climate damages will put a negative pressure on the economies of almost all regions, and trade flows are smaller when considering climate damages than in a naïve baseline that ignores feedbacks from climate change on the economy. Given the significant growth in baseline trade volumes projected over the coming decades, in absolute levels trade flows are still projected to grow when climate damages are accounted for. The economic consequences of climate change are especially strong in Africa and Asia, where high economic growth rates are combined with increased trade dependency and large damages from climate change. In terms of economic sectors, trade in agricultural commodities is projected to be relatively strongly impacted by climate damages, as these goods are heavily internationally traded.

The results of this study show that in the most affected countries exports decline more than imports and GDP and this will weaken their trade position. In contrast, producers in the least affected countries can improve their competitive position on both domestic and export markets. Therefore, despite being negatively affected by climate damages, a region may increase its competitiveness if other competitors for a certain market are more severely damaged or decide to specialise in the production of other goods.

Focusing on the impact of agricultural damages from climate change on food products, and using Revealed Comparative Advantage (RCA) as an indicator of regional competitiveness, this paper finds that while the ranking of comparative advantage is largely unchanged by climate change damages on the agricultural sector, there are significant effects for some countries. The effects are particularly large for the regions that are most specialised in food and agricultural products.

The regional changes in comparative advantage are driven by complex interactions in the economic system, where all sectors in all regions are intricately tied together and where climate damages affect all parts of the economy. Countries that have larger domestic markets and more diversified trade patterns can absorb climate shocks better than countries that are more specialised. There are numerous interactions between regions and sectors that make it impossible to establish rules of thumb on the competitiveness impacts of climate damages, but it is clear that the relative impacts in a region compared to its trading partners matter more than the absolute size of the regional damages. A region may improve its competitive position if other competitors for a certain market are more severely damaged or decide to specialise in the production of other goods. This highlights the need for each region to understand the direct impacts of climate change on their sectoral production and on their trade flows, but also the possible impacts of climate change on regions they are competing with for specific markets.

The paper also considers the role of trade as an “adaptation instrument” to climate change. By modifying their imports and exports, each region can partly adapt to the changes in domestic conditions due to climate change. For some regions, this is a crucial mechanism to limit the costs of climate change. The paper analyses the economic effects of a preliminary counterfactual scenario without trade flexibility in which changes in imports and exports cannot be fully used to adapt to climate change impacts. This scenario shows the extent to which trade as an endogenous adaptation mechanism plays a role in mediating the economic consequences of climate change. The results show that the global costs of climate change would be higher without trade flexibility, although not very much. However, there are differences both in the direction and size of the effects of limiting trade adjustments. Many of the regions that are projected to be most severely affected by climate change will suffer a further reduction when trade adjustments are not possible, most notably the South and South East Asia region. Other regions have a net gain from removing trade flexibility, primarily from maintaining their export revenues.

This paper only presents results from one single model and baseline. More robust quantitative insights require a more elaborate modelling analysis, using multiple scenarios on the major modelling assumptions, and ideally comparing different models. Nonetheless, the paper highlights the important effects that climate change will have on economic activities and on competitiveness as well as its role as an adaptation mechanism. By being aware of how climate impacts may affect its economy, not just through impacts on its production factors but also on trade, countries can design climate and trade policies that are aligned and thus avoid the worst climate damages at least cost.

1 INTRODUCTION

The atmospheric effects from continued greenhouse gases (GHG) emissions will lead to changes in the climate system (IPCC, 2013). Higher global surface temperatures and changed weather patterns are projected to accelerate the melting of glaciers, lead to rising sea levels, and to result in more frequent temperature extremes and longer-lasting heat weaves in certain parts of the world, among other effects. These impacts will have significant economic consequences for regions around the world, with large changes in sectoral and regional production and consumption (OECD, 2015) and hence on international trade.

Recent analysis by the OECD projects that the trend of economic integration and intensified global trade will continue in the future, albeit at a slower pace than in the last decades (Chateau et al., 2015). In the long run, global trade and its relative size to global income are driven by (i) transportation and communications costs (including "transaction costs"), (ii) income growth and changes in preferences, (iii) sectoral comparative advantage in production of goods and services, and (iv) trade policies and trade agreements (Feenstra, 1998). Changes in each country's specialisation depend ultimately on differences in these drivers amongst countries. The products in which countries specialise are determined by the availability of inputs used in the manufacture of different products and by access to different technologies. As such, specialisation is strongly driven by unevenly distributed natural resources across the globe.

Climate change will affect some of these elements, thereby changing trade and specialisation patterns through different mechanisms. Some climate impacts, such as higher frequency of extreme events or rising sea levels, will have direct impacts on trade as they will affect transport and distribution chains. Further, changes in factors of production of economies (i.e. land, labour, and capital) will affect production structure and trade specialisation. But, climate change is also expected to have indirect impacts on trade, as all regions and sectors are linked through inputs in production and trade in produced goods and services.

On the policy side, while climate change and trade policies are not necessarily directly related, mitigation policies will affect trade. Simultaneously, trade policies will also change emissions. Both topics have been dealt with in the literature (OECD, 2007, 2008, 2009; Copeland and Taylor, 2004; Cosbey and Tarasofsky, 2007; WTO-UNEP, 2009). However, dedicated analyses that look at the long-term impacts of climate change on international trade, and at how international trade affects the economic consequences of climate change impacts, are still very scarce. Bosello and Parrado (2014) show that the economic consequences of climate change depend on the possibilities to adapt international trade patterns. Schenker and Stephan (2014) find that funding adaptation in developing regions can reduce climate change costs as developing regions profit from receiving adaptation funding and high and middle income donor countries will generally benefit from improved terms-of-trade. Liu et al. (2014) study the role of trade in analysing the impacts of possible future irrigation shortfalls.

This paper specifically aims to shed light on how climate change damages will affect international trade in the coming decades, and on how international trade affects climate change costs. It first surveys the direct effects of climate change on the trade infrastructure. Then, the indirect impacts resulting from the economic consequences of climate change will be investigated in detail.[4] Finally, the paper will illustrate that international trade plays a role in keeping the costs of climate change as low as possible; it shows that trade also functions as a mean of adaptation to climate change as it allows economies to adjust to changing economic conditions.

The analysis of sectoral and regional economic changes in this paper relies on a dynamic computable general equilibrium modelling tool – the OECD's ENV-Linkages model – to draw global economic scenarios up to 2060.[5] These scenarios can be used to analyse the linkage between trade and climate (see Annex I for a brief description of the model and Chateau et al., 2014, for more details). This multi-regional and multi-sectoral dynamic general equilibrium model has been recently enhanced to consider the impact of climate damages on the economy (OECD, 2015). CGE models are traditionally well-suited to the type of analysis in this report, as they focus on linkages between economic sectors in various regions. This type of model is based on national accounts and international trade flows at sectoral level. The paper focuses on climate change impacts on trade of goods and services among countries, as opposed to capital flows and migration, both important issues but outside the scope of this paper.

This paper is structured as follows. Section 2 presents a projection of world trade and specialisation patterns in the coming decades, as projected by ENV-Linkages, without considering how these trends are affected by climate change. Section 3 then summarises the main direct impacts of climate change and presents results on indirect impacts as quantified in the model. Section 4 discusses how these changes in trade flows can be explained by the different mechanisms that drive trade patterns, including macroeconomic competitiveness and relative comparative advantage at the sectoral level. Section 5 complements this analysis by looking how the projected changes in trade patterns help in keeping the costs of climate change as low as possible, i.e. the role of trade as an adaptation mechanism. Section 6 provides some concluding remarks.

2 THE EVOLUTION OF INTERNATIONAL TRADE IN THE COMING DECADES

The ENV-Linkages model projects developments of economic activity at the sectoral and regional level until 2060 (see Annex I for further details on the model structure). Sectoral economic activity is projected using a production function for economic sectors, a utility function for households and international trade flows, with macroeconomic closure, i.e. all commodity flows have an origin and a destination, and are coupled to a reverse financial flow.

The projection of how international trade patterns will evolve is a core element of the ENV-Linkages model. A central assumption on the representation of international trade in the model is the so-called Armington assumption: domestic and foreign goods and services are considered to be imperfect

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4 Changes in trade patterns may also have a feedback effect on the climate as emissions will likely change in the future as centres of production relocate and shipping routes change. This topic is however outside the scope of this report.

5 The use of one central projection of economic developments with one specific assessment of the impacts of climate change implies that the quantitative results presented in this paper are mostly indicative; more robust quantitative insights would be gained from studying multiple scenarios and comparing different models.

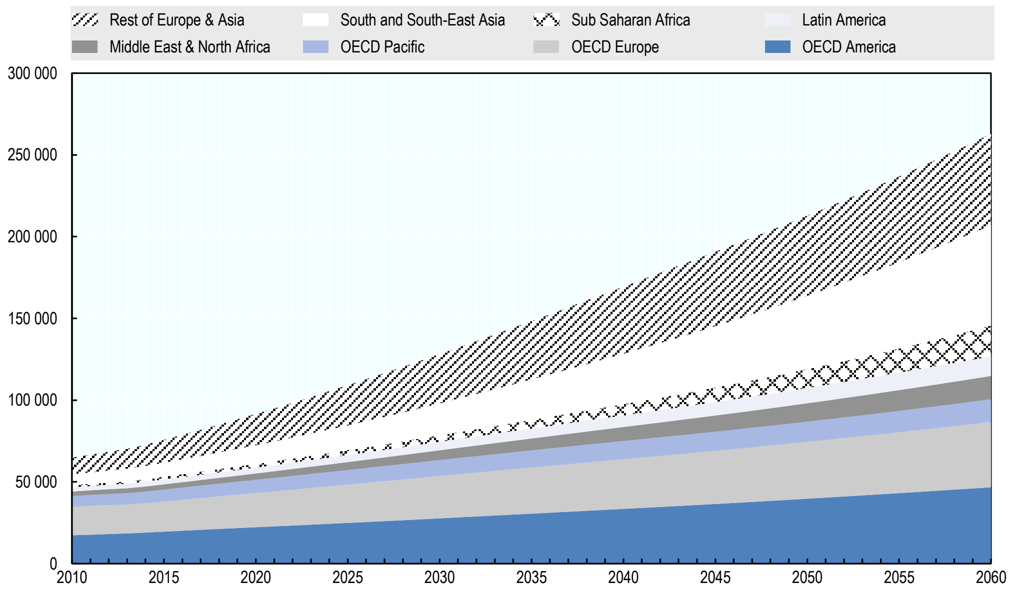
substitutes. This approach, which is common in CGE models, can mimic plausible levels of bilateral trade by differentiating the price of each good across countries. The model abstracts from an explicit representation of international capital markets, and instead assumes specific pathways for regional current account balances. This latter assumption implies that regional trade balances follow an exogenous path and real exchange rates will adjust in each period to reproduce these balances, and thus maintain model closure.6

The primary drivers of changes in global trade and specialisation patterns in the coming decades are the evolution of economic performance, population growth and demographic changes. Figure 1 shows the projected evolution of regional GDP and trade along the no-damage baseline projection. This baseline, developed for the CIRCLE project, does not contain environmental feedbacks and is detailed in OECD (2015).

Figure 1. Trend in real GDP in the no-damage baseline projection

Panel A. Evolution over time

(Billions of USD, 2005 PPP exchange rates)



Source: OECD ENV-Linkages model.

Over the next half century, world GDP is projected to grow on average around 3% per year, with declining rates in many countries in the last 20 year of the period. The trend GDP growth for the OECD region is projected at about 1.8% annually until 2060, and growth in emerging economies will continue to outpace the OECD, but the difference will narrow over coming decades as income levels in emerging economies catch up to those in the OECD. Near the middle of the century fast growth in Africa is expected to be the prime source of global economic growth. As a result, the next 50 years will see major changes in country

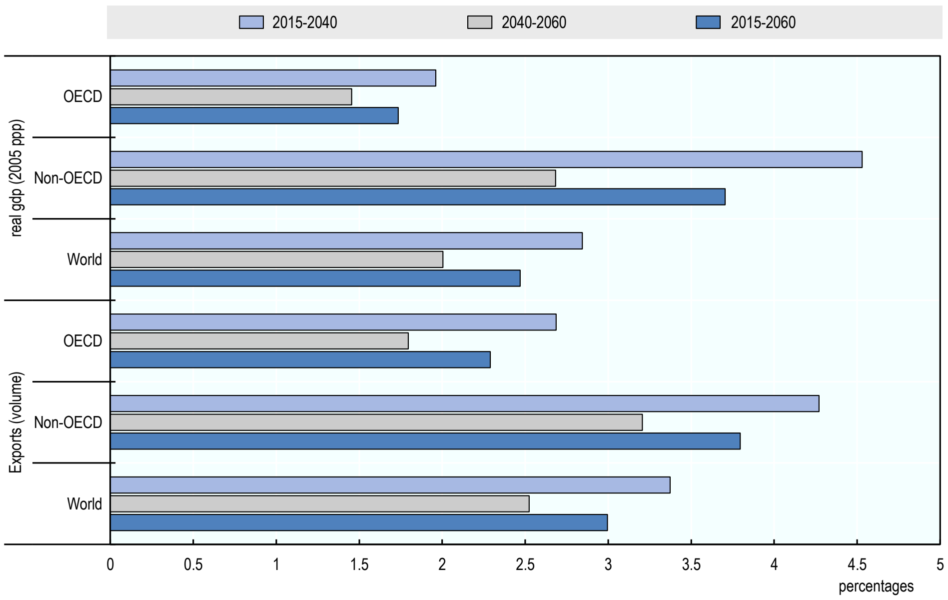
[6] It is a common assumption in CGE models to decouple international capital markets from international goods markets. In this context current accounts are exogenously given. Hence, the real exchange rates are the "macro" variables that equilibrate trade balance constraints and there are no financial variables in the model. The baseline real exchanges rates of emerging and developing economies progressively increase relative to those of OECD, reflecting a Balassa-Samuelson effect. This effect comes from high productivity growth in sectors that produce tradable goods, which will in turn drive wage increases in the slower growing non-tradable sectors. Hence, domestic price levels increase, and thus also relative prices vis-a-vis other countries, i.e. the real exchange rate.

or region shares in global GDP. The faster growth rates in emerging and developing economies imply that the combined GDP of present non-OECD economies are projected to account for around 70% of world GDP in 2060 versus 50% in 2015.

In line with the long-term economic growth projections by the OECD Economics Department (Chateau et al., 2015), growth in trade (gross exports of goods and services) is projected to continue to outpace GDP growth over the next 45 years with world trade estimated to grow at around 3% annually. The projected global trade-to-GDP elasticity is assumed to be around 1.2 for all goods and services (1.35 for goods and 1.15 for services), over the whole period. Thus, although trade is projected to increase more rapidly than income, this assumption could be seen as low relative in comparison to the historical values of 1.6 for goods between 1950-2009 or the projected value of 1.4 for goods for 2012-2060 calculated in the context of the OECD@100 project (Chateau et al., 2015).7 The more conservative approach adopted in this report is in line with the more pessimistic story on international trade in the Economic Outlook of November 2015.

Panel B. Growth in GDP and exports

(Average annual growth rate)



Source: OECD ENV-Linkages model.

In terms of geographical distribution, there will be large shifts in trade patterns, reflecting among other things uneven developments in income across the globe as well as changes in comparative advantage (Table 1). China and India are projected to gain market shares in world trade over the next half century. Likewise, Africa, Indonesia and other Asian economies are projected to experience sizeable increases in trade shares, especially after 2040, reflecting rapid growth leading to larger economic size combined with low production costs. These gains in trade shares of emerging and developing economies are mostly at the expense of European Union. Contrarily, some OECD economies, including the United States and OECD Pacific, are projected to see their trade shares relatively constant over the period.

7 Technically two assumptions done in the baseline construction explain our conservative view about the future trade to GDP elasticity: firstly in this report and contrarily to the OECD@100 projection no new trade policies and agreements are assumed after 2010, secondly the baseline assumes only small changes will occur in transaction costs for manufacturing goods in non-OECD countries.

The changing geographical distribution of trade is also featured by changes in the relative importance of trading partners (Figure 2). The expected shift of wealth creation from OECD to non-OECD countries will have important implications for trade patterns. While currently about half of total trade flows in bilateral terms took place within the OECD area, the share of bilateral trade among OECD members is expected to nearly halve by 2060. Instead, by 2060 trade among non-OECD economies is projected to more than double, to account for approximately one-third of global trade. The growing share of non-OECD countries in world GDP is one driver for this, but it is also because non-OECD countries will progressively adopt more similar production structures to those in the OECD, so that they can trade between each other instead of trading with OECD partners.

Table 1. Geographical distribution of trade in the no-damage baseline projection

(Regional gross exports as share of world exports)

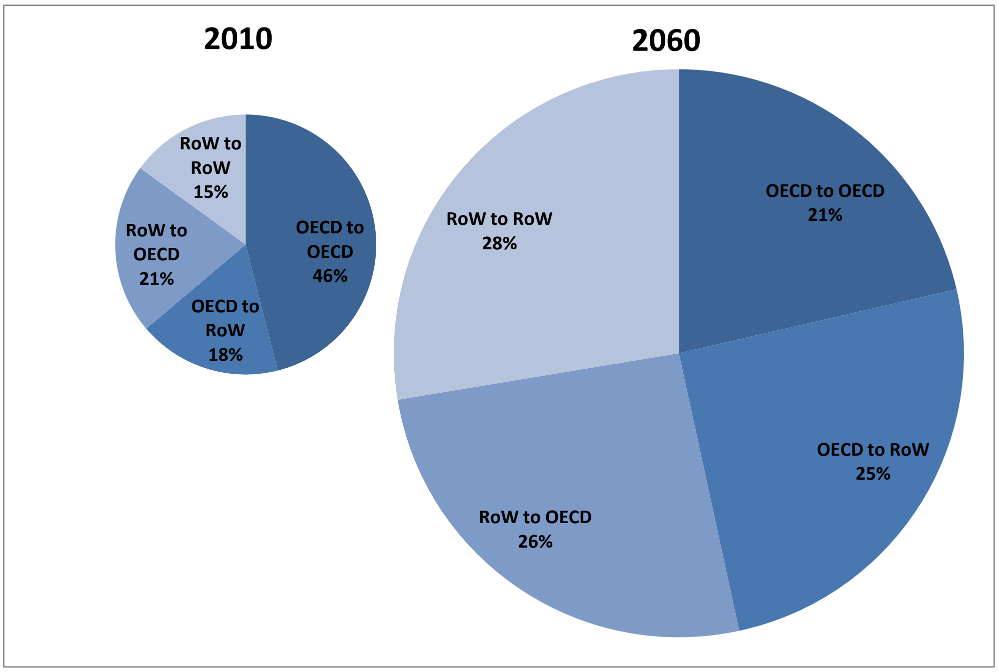
	2015	2040	2060
USA	11%	10%	10%
Canada	3%	2%	2%
Mexico	2%	2%	2%
OECD Oceania	1%	2%	2%
European Union	34%	26%	22%
Other OECD	4%	3%	3%
OECD Asia	8%	6%	5%
Other Europe	3%	2%	2%
Caspian	1%	1%	1%
Other Africa	2%	4%	7%
Brazil	1%	1%	1%
Other Latin America	2%	2%	3%
Mid. East & N. Africa	5%	5%	5%
India	1%	3%	4%
Indonesia	1%	1%	2%
China	13%	18%	18%
Other ASEAN	6%	6%	8%
Other Asia	3%	4%	5%

Source: OECD ENV-Linkages model.

Changes in sectoral trade patterns are driven by differences in income growth, but also by convergence in consumption patterns. As shown in Annex II, the baseline scenario will project a convergence in consumption patterns across countries that imply, among other things, a large shift away from consumption of food and necessary products towards services in emerging economies. Convergence in consumption patterns is projected to follow convergence in income levels. For production, there is more differentiation between countries in terms of access to technologies, factor endowments and productivity levels of production. Hence, production patterns evolve more slowly, and international trade patterns adjust to equate demand and supply in all regions. As a consequence, EU countries are projected to lose market shares for almost all goods (see also Figure AII.4 in Annex II), while non-OECD East-Asian countries and African countries are projected to gain market shares in manufacturing goods and Latin American countries in textiles and food products (but not necessarily in raw agricultural goods).

Figure 2. Bilateral trade between OECD and non-OECD countries in the no-damage baseline projection

(Regional gross exports at FOB prices as share of world exports)



Source: OECD ENV-Linkages model.

3 IMPACTS OF CLIMATE CHANGE ON DOMESTIC ECONOMIES AND INTERNATIONAL TRADE

The physical impacts of climate change will have direct as well as indirect consequences for trade. Direct effects encompass the effects of climate change on trade-relevant supply, transport and distribution chains, which could become manifest in damages to trade infrastructure from more frequent extreme weather events or rising sea level, for example, or through opening up new trade routes, e.g. in the Arctic. Indirect impacts for trade will primarily result from the economic consequences that climate change will bring about. Climate change is expected to impact the production of goods and services through changes to the factors of production of economies, i.e. land, labour, and capital. Climate change may also make available new factor input and natural resource endowments, such as fossil fuel reserves that had been inaccessible beforehand. Both direct and indirect effects of climate change on trade will likely lead to changes to the comparative advantage of economies, hence trade flows and patterns.

3.1 The direct impacts of climate change on international trade

Climate change will impact trade through a number of channels, not all of which can be easily quantified. This section outlines some of the main impacts, based on a brief review of the literature. One prominent explanation for the rise in international trade in the last decades was a decline in international transportation costs (Hummels, 2007). One key direct effect of climate change is that supply, transport and distribution chains might become more vulnerable to disruptions due to climate change, thereby affecting future international trade patterns. Extreme weather events, for instance, may lead to the temporary shutdown of ports and transport routes; they might also damage infrastructure critical to trade and thus have longer-lasting effects. These and other interruptions can lead to delays, increase the costs of international trade and could lead to a shift in trade patterns as companies involved in trade seek alternatives to increase reliability of shipping (WTO, 2009).

Although the literature on the link between climate change and trade is limited and mostly qualitative, there is high agreement among experts that climate change will on balance negatively affect transport infrastructure. According to reports surveyed by the IPCC (2014), climate change will affect all forms of transport relevant for international trade, including seaborne transportation, land-based transport modes, and aviation. There is only a small amount of research that points to the potential positive consequences of climate change on trade infrastructure, and supply, transport and distribution chains.

Trade-relevant impacts to land-based transportation from climate change may become manifest in faster degradation of road and bridge infrastructure, and shorter availability of transport routes through permafrost zones (IPCC, 2014). Bridges will be particularly prone to damage from sea level rise and changes in long-term flow regimes if authorities do not encourage necessary investments in adaptation. In the United States, for example, engineers typically design bridges to endure storms that have a historical probability of occurring only once or twice every 100 years. However, past climatic observations may no longer reliably predict future impacts due to climate change. Extreme weather events, including storms, may take place every 50 or even 20 years by the end of the century if global warming continues (NRC, 2008). In addition, heat stress and a higher number of freeze thaw cycles may accelerate the degradation of paved roads. Higher temperatures will likely contribute to the melting of permafrost, shortening the availability of transportation routes through zones of cryotic soil (WTO, 2009; IPCC, 2014).

Airborne transport of goods for international trade might be impacted by climate change, for instance through damage to or impairment of the operations of airports. Research suggests that sea level rise, increased storminess, and extreme precipitation induced by climate change can affect the operations of airports, lead to more frequent disturbances, and affect infrastructures in weather-exposed or low-lying areas. Higher temperatures may also reduce aircraft lift, making airports adapt runways and air companies to change aircraft types or maximum payload with climate change.

Maritime shipping, which accounts for around 80% of global trade by volume and more than 70% of global trade by value (UNCTAD, 2014), could also experience some negative consequences from more frequent port closure caused by higher temperatures, sea level rise, increased storms and increased precipitation. Increasingly severe storms along certain shipping routes may necessitate the use of alternative shipping routes or additional safety measures, affect passage through locks, and increase the maintenance costs for ships and ports (IPCC, 2014). Dependent on location, physical impacts from climate change might also affect future inland navigation.

At the same time there could be positive impacts of climate change on maritime shipping. One high-profile example is the potential further opening of Arctic shipping routes, including the Northeast Passage, the

Northwest Passage, and the Transpolar Sea Route, for longer periods. There is currently little commercial shipping through the artic area. However, experts agree that Artic ice-melting will very likely continue through this century. A growing number of papers find that reduced ice cover would permit ships with light icebreakers access to pretty much anywhere in the Arctic Ocean by 2040. This implies that there is a change in the sea route for transportation of trade, by opening the Arctic sea routes.8 For the relevant bilateral trade routes, the availability of Arctic shipping paths could hence lead to decreases of shipping costs, reduce transport time, and improve reliability of shipping, among others.

For trade between Europe and Asia, the conventional sea route is mainly the Suez Canal Route, which connects the Mediterranean and the Eastern Asia. The emerging alternative through the Arctic region is the Northern Sea Route (NSR), which is also called as Northeast Passage. Bekkers et al. (2015) anlyzes that the northern route would reduce the distance from Japan to northern European countries by 37%, from South Korea by 31%, China 23%, and Taiwan 17%. The countries in Europe that will gain most from the new sea route are those with access to ports on the North Sea and the Baltic. For South Asian countries and southern European countries, the conventional southern route will still be shorter.

For trade between America and Asia, the traditional route is via Panama Canal and the emerging alternative is the Northwest Passage. Compared with the traditional route, the Northwest passage is expected to cut the distance by around 25%, saving up 10 days.

Such distance reduction can have significant implications on international trade patterns. Transportation cost is an important factor to determine the trade pattern, and in turn the transportation cost is determined by variables such as distance, time, trade imbalances, trade volume and vessel size, competition, infrastructure, and piracy and other risk (OECD, 2011). Among such factors affecting the transportation costs, the distance has been regarded as one of the most important determinants. Many studies and literature confirmed this “distance decay” – the volume of trade declines as the distance between two countries increases, reflecting transportation costs of increased freight costs and increased length of transit.

If the new sea route becomes a viable alternative for large portions of the year, world trade patterns will alter, benefiting northern countries, and potentially causing a reduction in revenues for the current main trade routes such as the Suez Canal. Bekkers et al. (2015) investigate the hypothetical extreme scenario in which the artctic route becomes fully operational all year around, and project that roughly 8% of world trade goes through the Suez Canal, and that two-thirds of this volume could potentially go via the shorter Arctic route if that becomes permanently available. The northern route would then become one of the busiest shipping lanes in the world, increasing the economic and political importance of the Arctic. At the same time, it will put economic pressure on countries that benefit from shipping that uses the southern route, but also some countries in eastern and southern Europe would experience a drop in trade because of the comparatively longer distances their exports and imports would need to travel. Over time, the opening of the Arctic route will have knock-on effects on jobs and prosperity in all the countries concerned, but it is predicted that this will be a gradual rather than sudden process.

However, it is clear that in the coming decades a full opening up of the Arctic route is not plausible. The remoteness of the locations, harsh weather conditions, short winter days, lack of infrastructure and uncertainty over how melting ice may affect the stability of the Arctic climate all make it difficult to predict how big an effect Arctic shipping may have on international trade. This remains a key area for further analysis.

8 Main Arctic shipping routes are North East Passage (NEP), North-West Passage (NWP), and Transpolar Sea Route (TSR). These are currently seasonal sea routes which has ice-free period only for summer. During summer, North East Passage and North West Passage are easily navigable whereas Transpolar Sea Route is navigable only with powerful icebreakers.

3.2 The indirect consequences of climate change on international trade

3.2.1 The regional economic consequences of climate change[9]

The report *The Economic Consequences of Climate* Change (OECD, 2015) provides a detailed global quantitative assessment of the macroeconomic and sectoral economic consequences of climate change (i.e. climate damages) for a selected number of impacts: changes in crop yields, loss of land and capital due to sea level rise, changes in fisheries catches, capital damages from hurricanes, labour productivity changes and changes in healthcare expenditures from diseases and heat stress, changes in tourism flows, and changes in energy demand for cooling and heating.[10] Here the main modelling results are summarised, to provide background for the analysis in the next section.

The modelling assessment suggests that market damages from the selected set of impacts are projected to gradually increase over time and rise faster than global economic activity. If no further climate change action will be undertaken, the combined effect of the selected impacts (in the climate damages scenario) on global annual GDP are projected to rise over time to likely levels of 1.0% to 3.3% by 2060, with a central projection of 2% (Figure 3). This range reflects uncertainty in the equilibrium climate sensitivity (ECS) – a measure indicating how sensitive the earth's climate reacts to a doubling of atmospheric CO_2 – using a likely range of 1.5°C to 4.5°C. Assuming a wider range of 1°C to 6°C in the ECS, GDP losses could amount to 0.6% to 4.4% in 2060.

Some sectors are directly impacted by specific climate impacts (e.g. services sectors are affected by health impacts, energy sectors by energy demand impacts). However, there are also substantial indirect impacts, such as changes in production in (energy-intensive) industrial sectors due to the full range of price changes that follow climate impacts or capital destruction from sea-level rise which affects all sectors through changes in the marginal productivity of capital. Of the impacts modelled in the analysis, changes in crop yields and in health (labour productivity) are projected to have the largest negative consequences on the macro economy, causing loss to annual global GDP of 0.9% and 0.8%, respectively, by 2060 for the central projection of the climate damages scenario (panel B).[11]

9 This section draws heavily on Chapter 2 of OECD (2015).

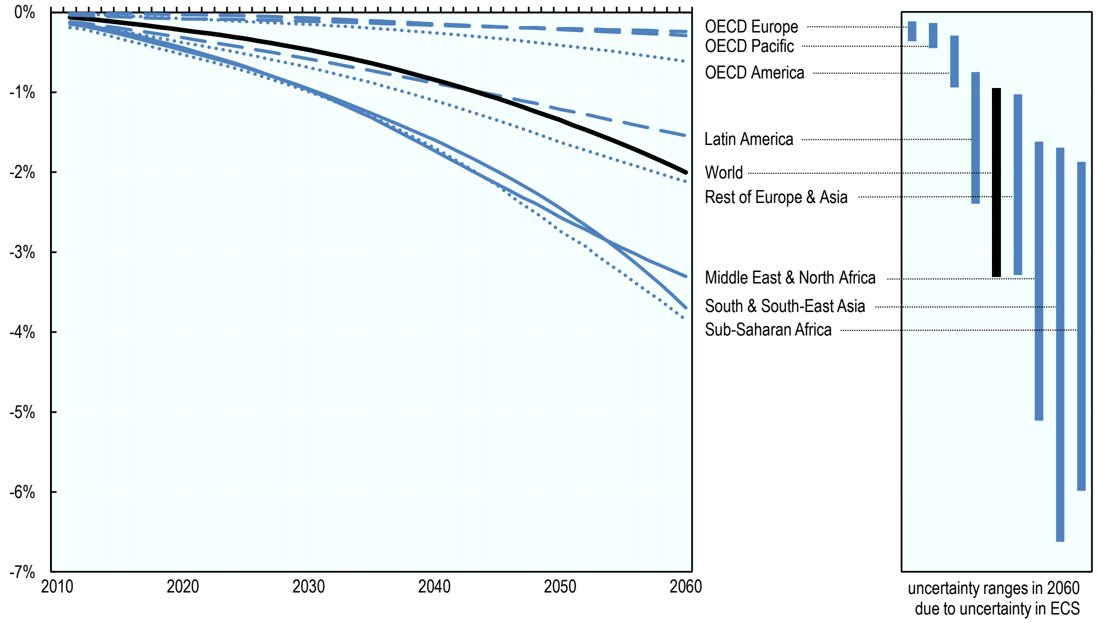
10 For an overview of how these impacts are covered in the ENV-Linkages model simulations, see OECD (2015). That report also highlights that there are numerous important impacts of climate change which could not be included in the modelling analysis and provides the broader context that surrounds these simulations, and the logic for ambitious policy action.

11 Including a CO_2 fertilisation effect reduces the agricultural damages to 0.6%, and the effect is projected to be especially strong in Africa (reducing agricultural damages from 1.5% to 1.0% by 2060 in Sub-Saharan Africa). Such effects are excluded from the analysis here.

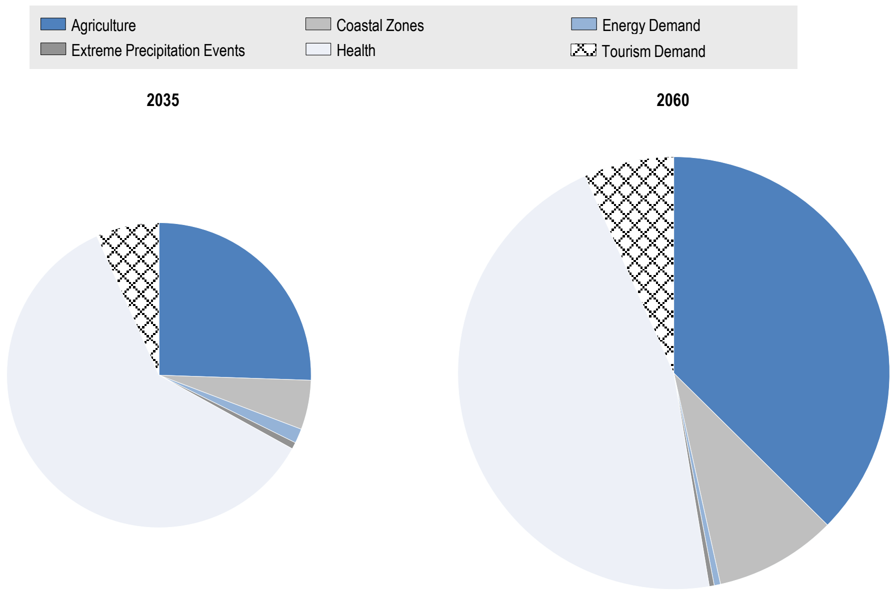
Figure 3. Regional damages from selected climate change impacts in the climate damages scenario

(Percentage change in GDP w.r.t. no-damage baseline)

Panel A. Evolution over time



Panel B. Attribution of global damages to different impacts



Source: OECD ENV-Linkages model.

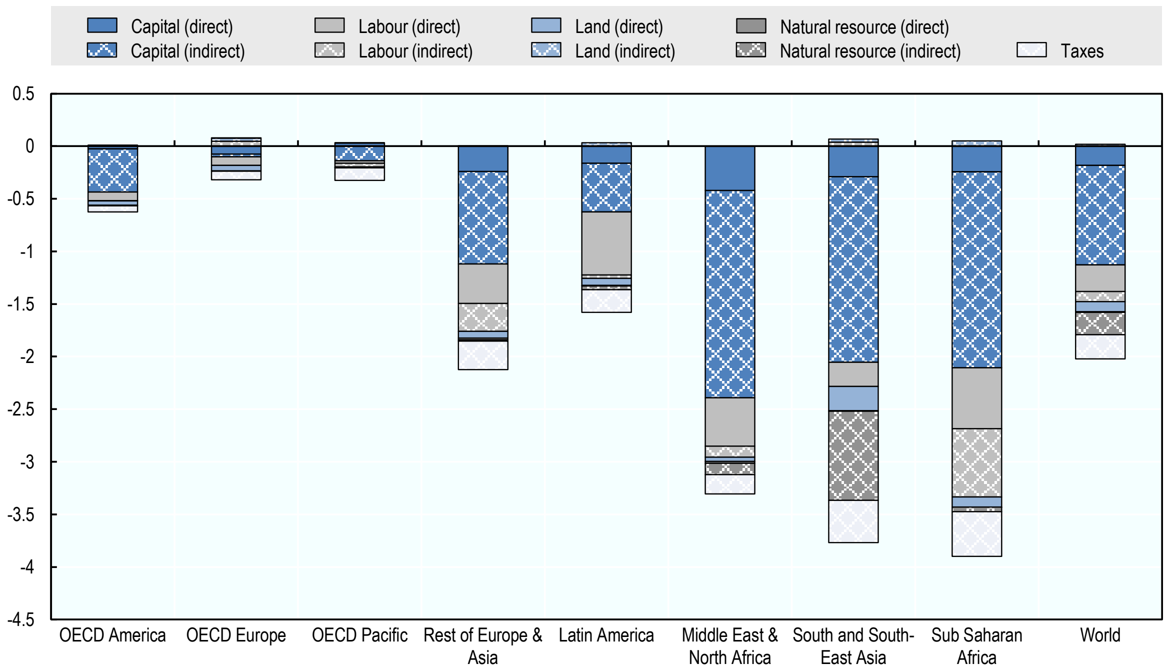
The GDP impacts as projected with the ENV-Linkages model can also be attributed to specific production factors. Climate impacts may directly affect labour, capital, land and natural resources, and the economic adjustment processes also result in changes in the contribution of tax revenues to GDP, even though there are no direct impacts of climate change on taxes. Figure 4 shows the decomposition of GDP losses according to production factor, with shading indicating the direct changes in value added of a production factor. These direct effects have been calculated by multiplying the percentage change in productivity and supply of these production factors at their no-damage baseline levels of use, i.e. before any endogenous market adaptation effects. The indirect effects (not hatched in Figure 4) are then calculated as the difference between the total effect and the direct effect.

In the model, total labour supply is assumed to be fixed, and land and natural resources are relatively inflexible in their supply, and hence direct effects more or less directly translate into GDP loses, although sectoral reallocation can still affect their overall contribution to GDP. An exception is the reduction of value added from natural resources in South and South-East Asia, which is attributed to the decline in production of a number of resource-dependant sectors, which is induced by the changes elsewhere in the economy.

For capital, the situation is different, as supply is flexible in the long run, as consumers can adjust their savings patterns. Thus, there is an additional effect, as changes in income levels affect savings and hence future capital accumulation. Thus, the climate impacts not only affect the level of GDP, but also the growth rate, through reduced capital accumulation. As can be inferred from Figure 4, capital losses are substantially larger than the other factor losses, and this can be attributed to these indirect economic effects. At the global level, almost half of the projected GDP loss of 2% can be attributed to the indirect effects on capital, which may be interpreted as growth effects. In other words, by 2060 the projected economic consequences on GDP levels and on GDP growth are of similar size.[12]

Figure 4. Sources of damages from selected climate change impacts by production factor in the climate damages scenario

(Percentage change in GDP in 2060 w.r.t. no-damage baseline)



Note: Plain areas denote direct effects and hatched areas the associated indirect effects.

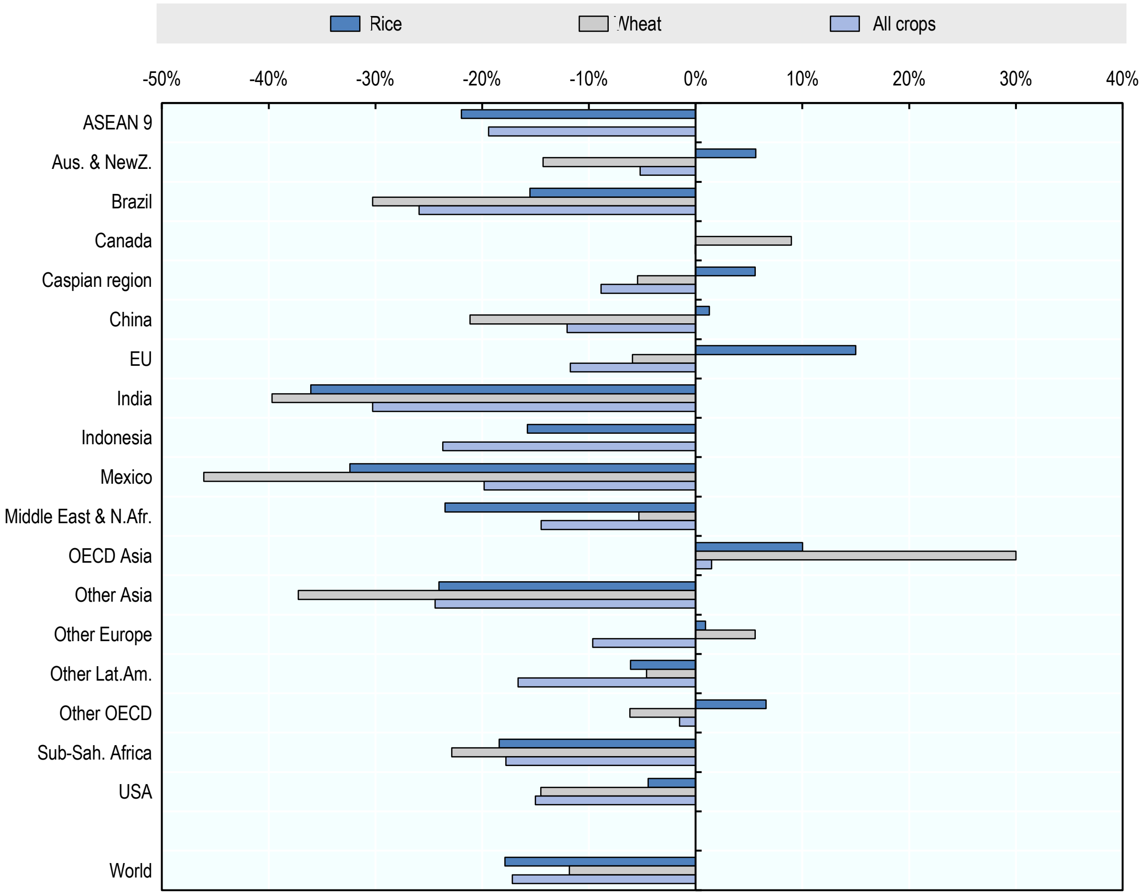
12 The growth rate effects of climate change are further explored in Section 3.1.3.

Source: OECD ENV-Linkages model.

Adverse impacts of climate change will affect all sectors of the economy, including those that are heavily traded internationally. Agricultural commodities may be particularly affected by climate change through increase in temperature and more frequent heat extremes. Further, changes in precipitation will in most regions likely lead to significant reductions in crop yields and hence, decreased crop output. For specific crops in specific regions, relatively small temperature increases, combined with increased rainfall, may benefit crop production. In order to examine the extent to which economies will be affected by the adverse impact of climate change on crop yields, Figure 5 illustrates the projected changes in yields in the climate damages scenario compared with the baseline scenario in 2060.

Figure 5. Impact of climate change on yields for selected crops in the climate damages scenario

(Percentage change in GDP in 2060 w.r.t. no-damage baseline)



Source: OECD ENV-Linkages model.

3.2.2 Changes in trade patterns due to climate change impacts

The economy-wide and sectoral consequences of climate changes discussed in the previous section have important implications for trade and specialisation across countries. To highlight this, this section compares the baseline with no climate change impacts trade projection with the scenario with climate damages.

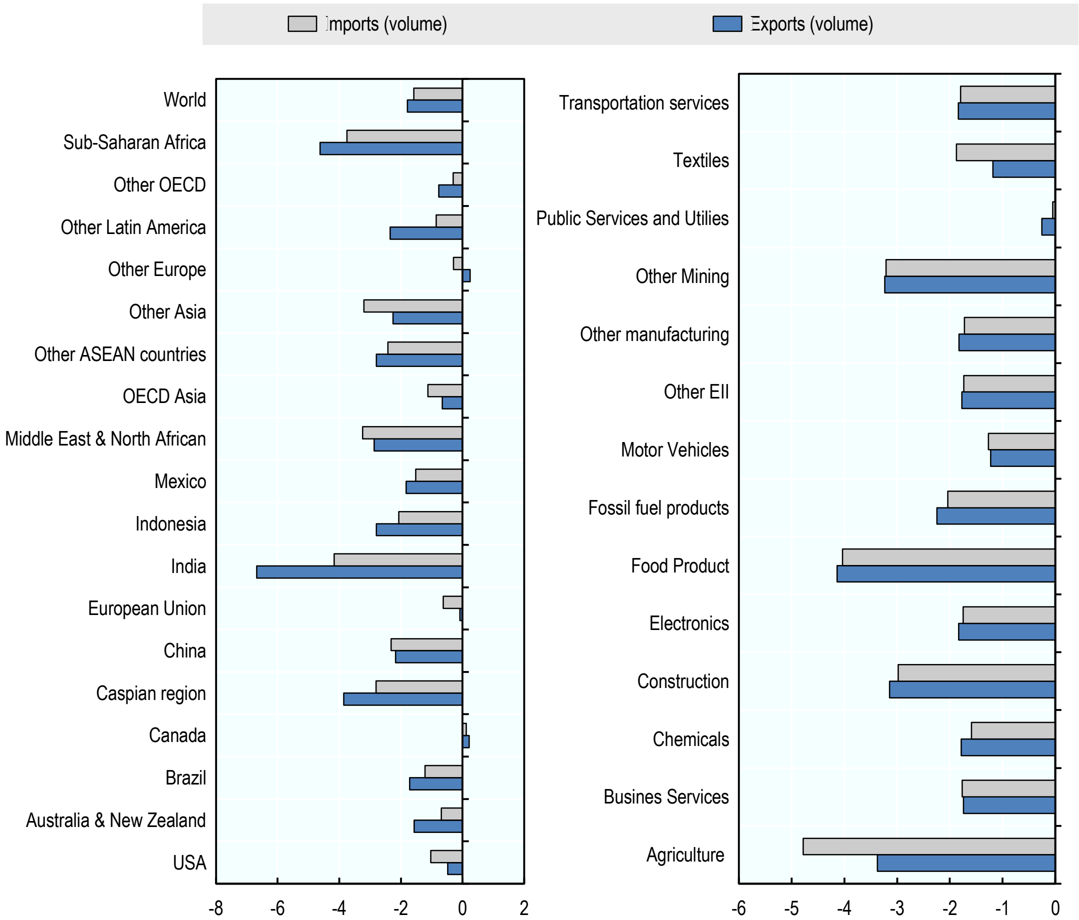
The volume of international trade is projected to be affected more strongly by climate change than global GDP. Figure 6 indicates that world trade (exports) may decrease by 1.8% in 2060, relative to the baseline without climate damage, while the global GDP would be reduced by 1.6% (expressed in 2010 USD using PPP exchange rates)[13]. One simple reason is that the African and Asian countries that are most affected by climate impacts (Figure 3) are also those that are projected to record growing importance in world trade over the next 50 years (see Table 1 and Figure 2).

Figure 6. Changes in trade volumes from climate impacts in the climate damages scenario

(Percentage change in 2060 w.r.t. no-damage baseline)

Panel A. By region

Panel B. By sector



Source: OECD ENV-Linkages model.

GDP losses are not the only channel through which climate change would impact international trade. The differences in impacts of climate damage on economic sectors also translate in changes in the composition of trade. As indicated in Panel B of Figure 6, trade in agricultural commodities is projected to be relatively strongly impacted by the negative climate damages, not least through the direct impact on crop yields.

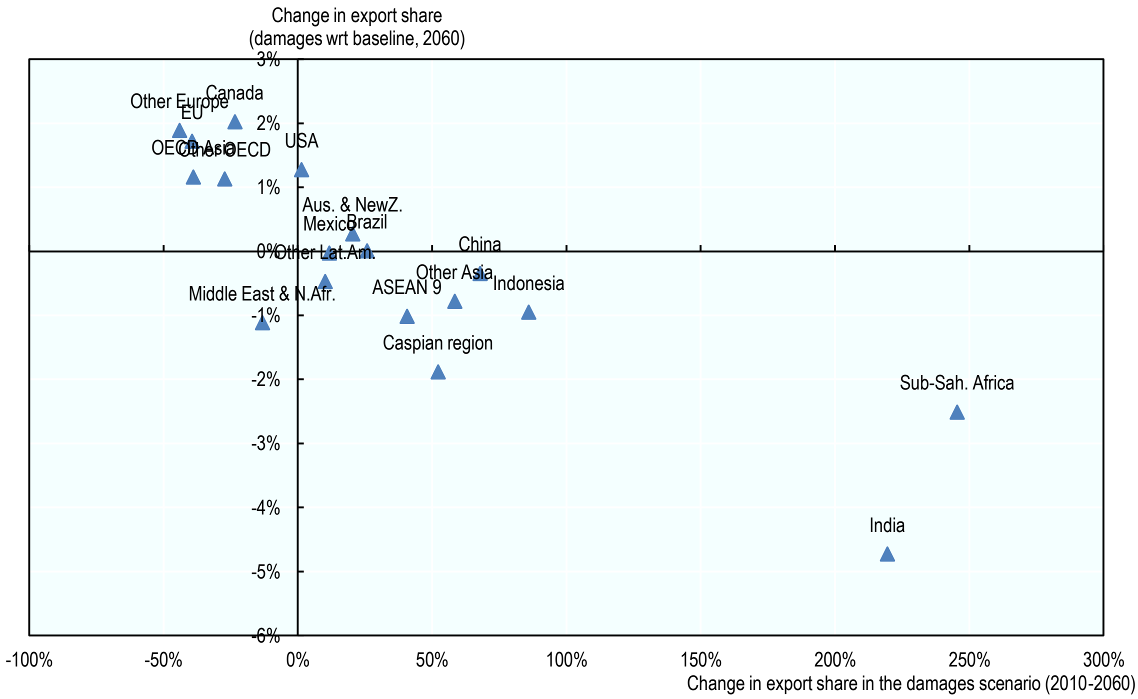
13 In Figure 6, the percentage change in global import volume is slightly different that the change in global export. This is explained by the fact that volumes in the model are expressed in constant 2010 USD and as the time horizon of the model will extend the price indexes for export and imports will deviate, only flows in current dollars are balanced at the world level.

Indirectly food product trade is also significantly affected as – at least in value terms – food is substantially more traded than its primary components, namely 'raw' agricultural products.[14] It is also worth noticing that trade in chemicals products is less reduced than trade of most of the other goods. One explanation is that farmers will try to compensate the losses in land yields consecutive to climate change through intensification and extensification. Ceteris paribus, this also leads to an increase in the use of fertilizers, which are included in the chemicals sector.

These sectoral and regional changes in trade flows are also reflected in changes in global export market shares. Figure 7 presents a country's potential export share under the baseline scenario as linked to the change in export share in 2060 under the climate change. Countries at the bottom on the left-hand side are expected to lose export market share in 2060 without climate change, with climate change projected to lead to even further decline. Generally, those regions that increase their export share in the baseline see a reduction in export shares from climate damages. The logical explanation is that these regions depend strongly on trade as a source of economic growth, leaving them vulnerable to shocks that negatively affect trade opportunities.

Figure 7. Change in export shares in the no-damage baseline projection and in the climate damages scenario

(Percentage change)



Source: OECD ENV-Linkages model.

14 In the model, processed food is categorised as food products, not as crops. Hence, the food products category includes meat, milk, vegetable oils, processed rice, sugar, other food, beverages and tobacco products.

4 UNDERSTANDING THE INDIRECT IMPACTS OF CLIMATE CHANGE ON INTERNATIONAL TRADE

As explained above, the indirect consequences of climate change on international trade patterns can be understood by looking at 4 key mechanisms: (i) changes in transportation costs; (ii) changes in macroeconomic competitiveness; (iii) changes in comparative advantage at the sectoral level; and (iv) changes in policies.

This section focuses on two main channels of trade impacts: *the macroeconomic channel* of the income effect, and *the sectoral channels* of the compositional effects. *Changes in international transportation costs* were reviewed separately in Section 3.1, but are not included in the modelling exercise. On balance, the literature review suggests that the quantitative effects by 2060 are relatively minor, especially in comparison with the significant indirect trade impacts of climate change, although for specific climate events in specific regions, temporary trade disruptions can be very significant.

Changes in policies, as an endogenous response to the projected macroeconomic and trade consequences of climate change, are explicitly excluded in the analysis. While it may well be the case that countries react to large changes in trade flows and losses to their domestic economies by revising their trade and other policies, these are not easily predicted, and deserve a separate study[15]. By excluding an endogenous policy response, the analysis here boils down to an assessment of the costs of inaction. This can then serve as a basis for assessing the benefits of policy action.

There are no direct measures of competitiveness and comparative advantage. For the macroeconomic analysis, changes in trade flows can be linked to a range of macroeconomic variables, including GDP and exchange rates. At the sectoral level, Revealed Comparative Advantage (RCA) is a common technique for providing information on the relative advantage or disadvantage of an economy in certain goods or services based on trade flows (Box 1).

Box 1. The Revealed Comparative Advantage (RCA)

An RCA indicator can be used to show more clearly how climate change-induced changes to factors of production affect gains and losses from trade that countries derive from domestic factor endowments. RCA is defined as the share of a region's exports of a set of commodities in the region's total exports relative to the share of the world's exports of these commodities in global exports. Technically,

$$RCA \equiv \frac{\mathrm{x}_{\mathrm{i,j}} \big/ \mathrm{X}_{\mathrm{'all',j}}}{\mathrm{X}_{\mathrm{i,'all'}} \big/ \mathrm{X}_{\mathrm{'all','all'}}} \equiv \frac{x_{ij} \big/ \sum_i x_{ij}}{\sum_j x_{ij} \big/ \sum_{ij} x_{ij}}$$

where x_{ij} denotes exports of product *i* by country *j* and 'all' refers to the relevant group of all products (i.e. all

15 For this study, the assumptions relative to trade policies are very conservative in the ENV-Linkages baseline projection. No new trade policies or trade agreements are implemented after 2010: tariff rates as well as export tax rates are assumed to stay constant over the horizon. In similar spirit, support to production (in agriculture and energy) that could be seen as indirect subsidies to domestic production are also kept constant, relative to the tax-basis. The only change in policies that is implemented in the baseline are energy and carbon policies as covered by the IEA in its "Current Policies Scenarios" presented in the World Energy Outlook 2013 (IEA,2013).

those that are exported) or all regions (i.e. all those that are exporting product *i*).

4.1 Income effect: changes in macroeconomic competitiveness of countries

Figure 8 shows that changes in GDP are generally well-aligned with the overall volume changes in trade at the macro level: countries whose national income deteriorates from climate impacts will scale down not only domestic economic activity, but also the volume of trade. Similarly, lower exports coincide with a lower GDP.

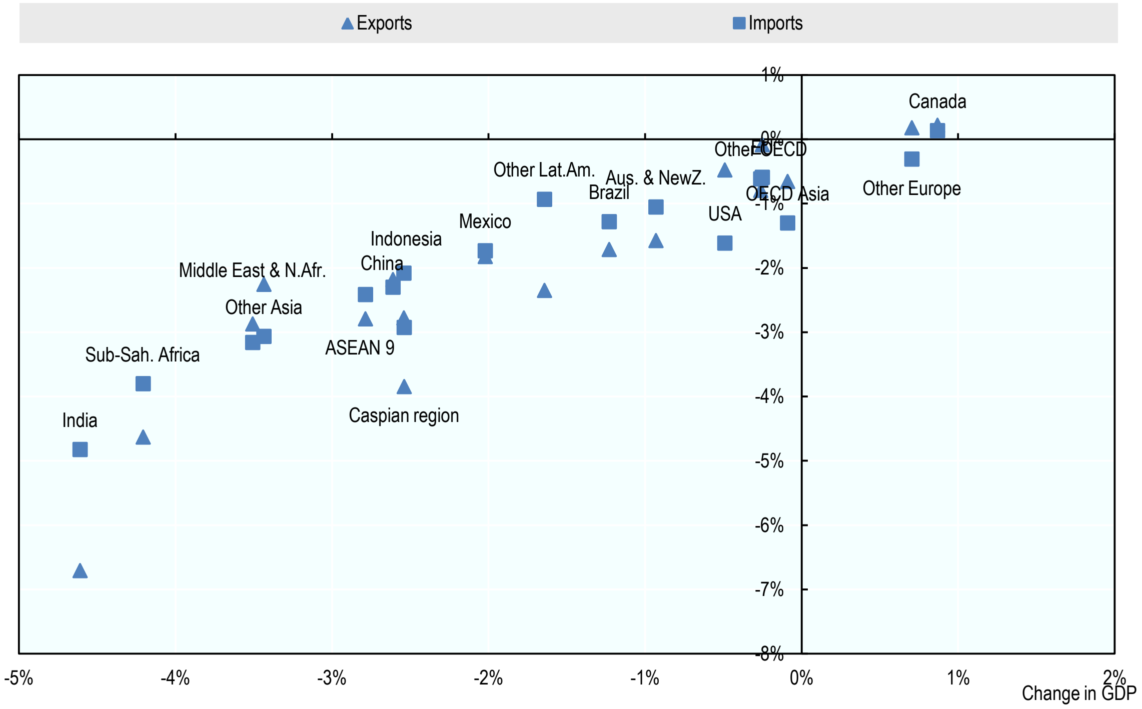
It is clear that for the most affected regions, India and Sub-Saharan Africa, especially, exports contract more than GDP. Given the strong impacts of climate change on these regions (cf. Section 3), their production costs rise and their macroeconomic competitiveness declines.[16] Imports are less affected in these regions, and in most cases even less than GDP. In these countries the large drop in domestic production is partially compensated through increasing the import share, in order to keep domestic consumption, and thus utility, as little affected as possible.

In contrast, regions whose macro economy is less affected by climate change (in this case regions with GDP losses of less than 1% in 2060), can increase their competitive position on their domestic market, i.e. import shares decline and imports fall more than GDP. At the same time, these regions have lower losses (or higher gains) for exports than for imports , which is indicative of their increased competitive position on the international market.

16 Two other regions that are substantially affected by climate change, Other Asia and the Middle East, defy this trend and have relatively small impacts on exports. These two regions are characterised by very particular specialisation patterns which partially shelters them against trade impacts.

Figure 8. Change in trade volumes and in GDP in the climate damages scenario

(Percentage change in 2060 w.r.t. no-damage baseline)



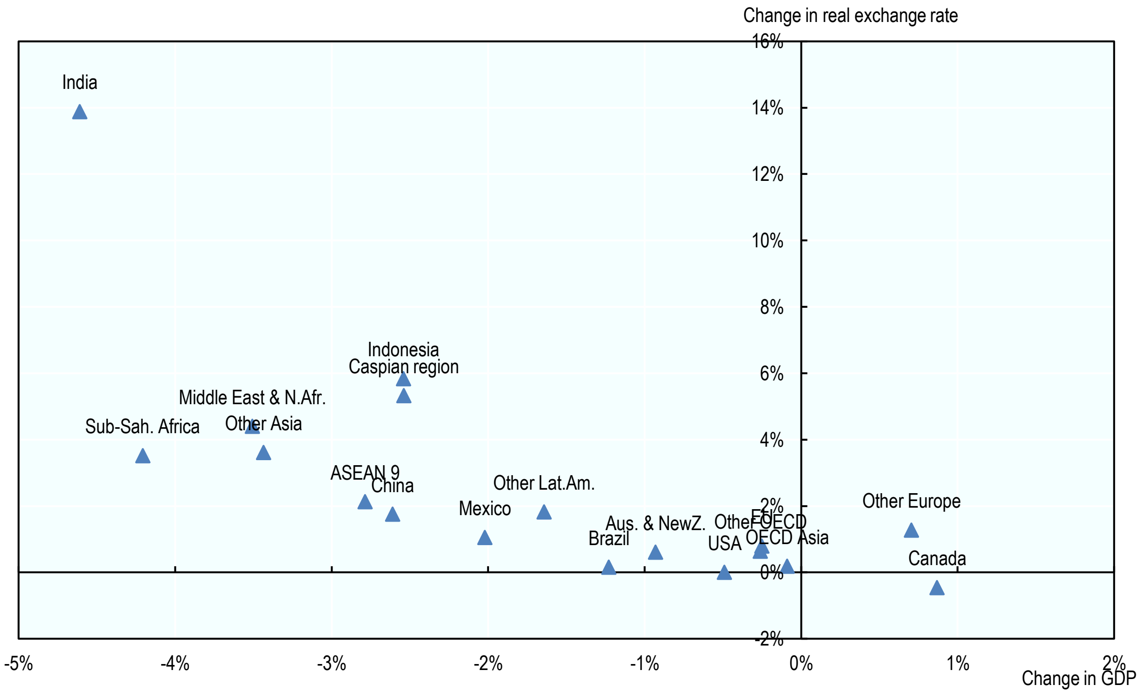
Source: OECD ENV-Linkages model.

Given the assumption of exogenous trade balances in the model, changes in trade flows alone cannot show all the mechanisms at work.[17] An important role in adapting to the climate impacts is through adjustments of the real exchange rate, which adjust endogenously to balance regional trade flows. Figure 9 highlights that in general large GDP losses are associated with strong increases in the real exchange rate vis-a-vis the United States. Increases in the real exchange rate in the worst affected countries imply that their exports become more expensive.

[17] The alternative assumption that trade balances adjust in response to climate impacts, instead of adjusting exchange rates, may influence the quantitative results but would not reverse the general insights.

Figure 9. Change in real exchange rates in the climate damages scenario

(Percentage change in 2060 w.r.t. no-damage baseline)



Source: OECD ENV-Linkages model.

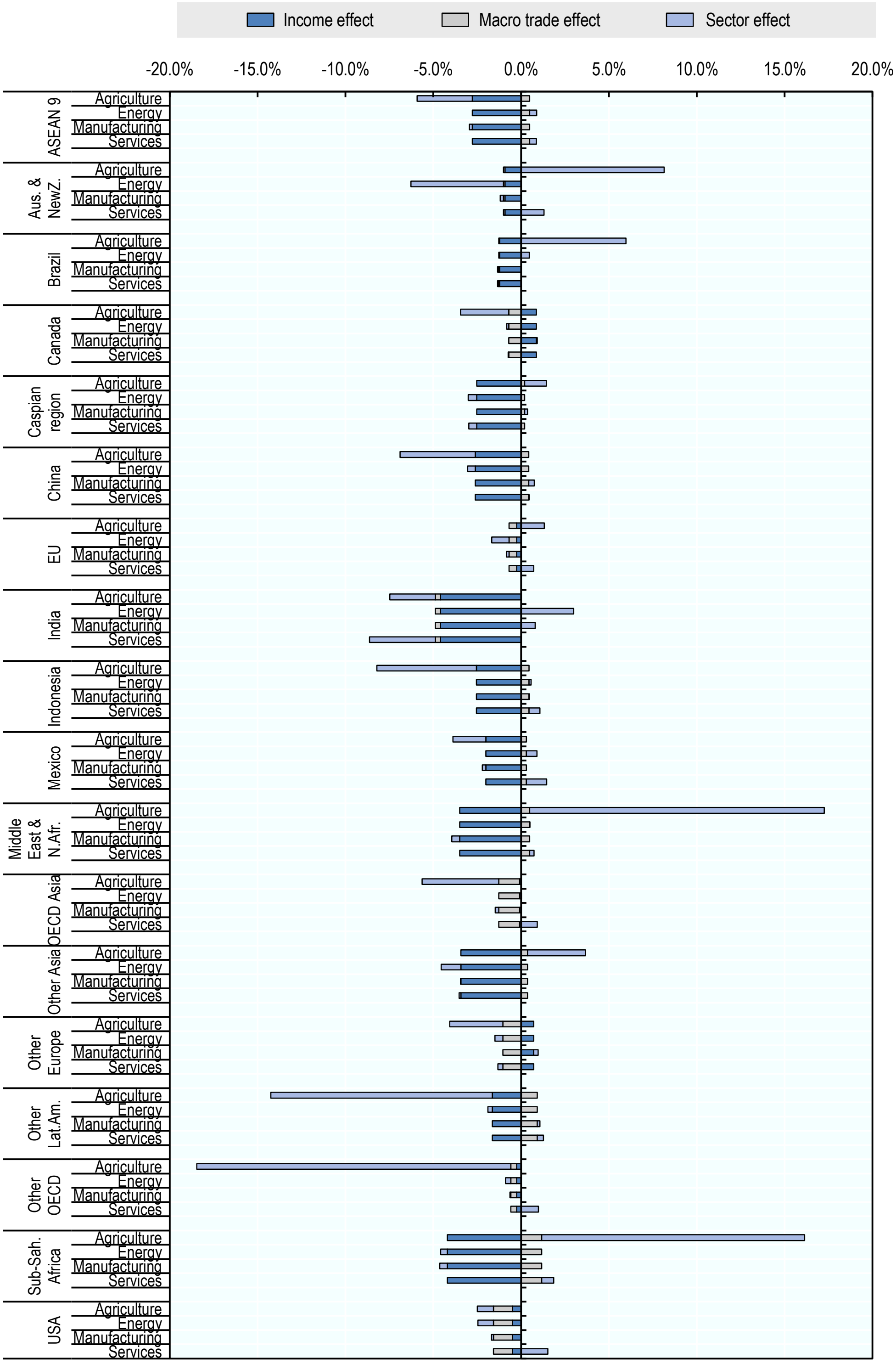
Changes in sectoral import patters are determined by a combination of macroeconomic and sectoral effects, as illustrated in Figure 10. The total change in sectoral imports is the sum of three effects. First, sectoral imports depend on the size of the economy; this income effect is calculated as the change in GDP. Secondly, total imports as a share of GDP may adjust to the new equilibrium; this macro trade effect is defined as the change in total imports minus the change in GDP. Finally, sector-specific effects will lead to adjustments of the sectoral composition of improts. In volumes, for each region these sectoral effects add up to zero across sectors.

With the exception of Other Europe, OECD Asia and the USA, total import volumes follow GDP, and the income effect is larger than the macro trade effect. In most cases, the macro trade effect is of the opposite sign as the income effect, reflecting the mechanism outlined above that regions adjust their imports to compensate for changes in domestic production costs.

For the agricultural sector, the sectoral effect dominates in almost all regions: changes in agricultural imports are predominantly determined by effects on the sector itself, not by changes in the macro economy. However, given that agricultural trade is a relatively small share of overall imports, a large percentage change in the sectoral effect for agriculture can be compensated by relatively minor opposite changes in the other sectors. It is striking to see that the sign of the sectoral effects varies widely across regions. This signifies that a detailed sectoral and regional analysis is warranted to explain what happens to sectoral trade flows. The next section will investigate these sectoral effects in more detail, with a focus on how agricultural trade is affected by agricultural impacts of climate change (while Figure 10 shows the consequences from the whole set of climate impacts, including those on agriculture, labour productivity and others).

Figure 10. Change in sectoral imports in the climate damages scenario

(Percentage change in 2060 w.r.t. no-damage baseline)



Source: OECD ENV-Linkages model.

4.2 Compositional effects: changes in comparative advantage in agricultural commodities

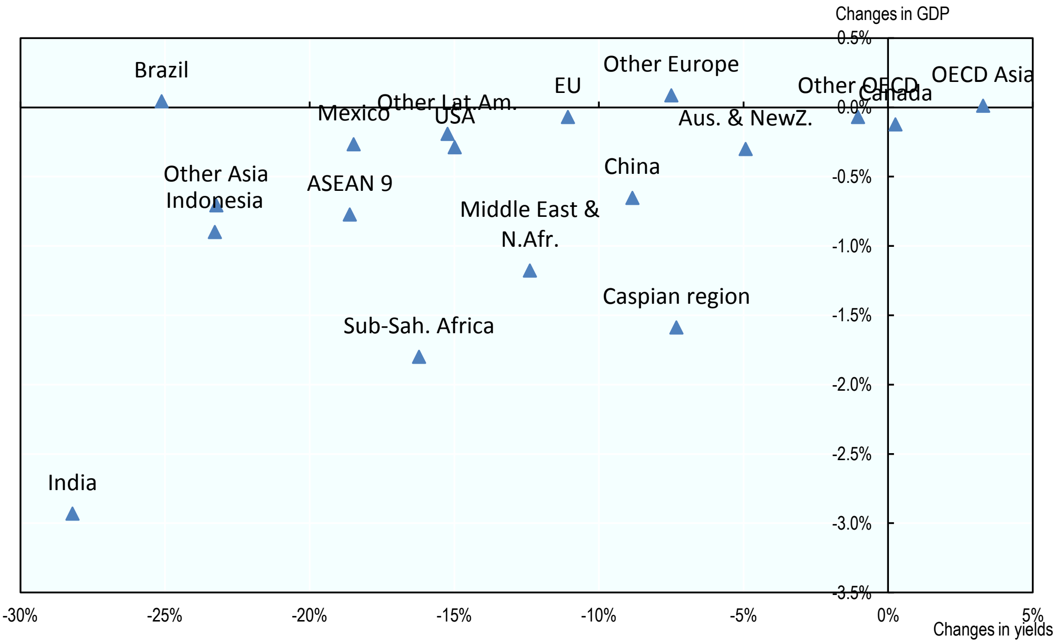
The previous section has illustrated the main macroeconomic effects of climate change on trade. This section instead focuses on sectoral and compositional effects by studying changes in comparative advantage. Many effects interact in the model both in terms of sectoral changes and consequences of the different impacts. This makes it hard to analyse the impacts on all sectors and from all climate damages together. As a case study, this section therefore focuses on climate change impacts on crop yields and their impacts on trade in food products (Box 2).

Box 2. Macroeconomic consequences of agricultural impacts

The analysis in this section focuses on changes in agricultural exports, and specifically food products (which includes all processed foods, see footnote 10). In order to clarify the main mechanisms at work, this analysis is carried out with a simulation in which only agricultural damages from climate change are included, and the other damages, such as those on labour productivity, are excluded.

Figure 11. Change in aggregate crop yields and GDP in the agricultural damages scenario

(Percentage change in 2060 w.r.t. no-damage baseline)



Source: OECD ENV-Linkages model.

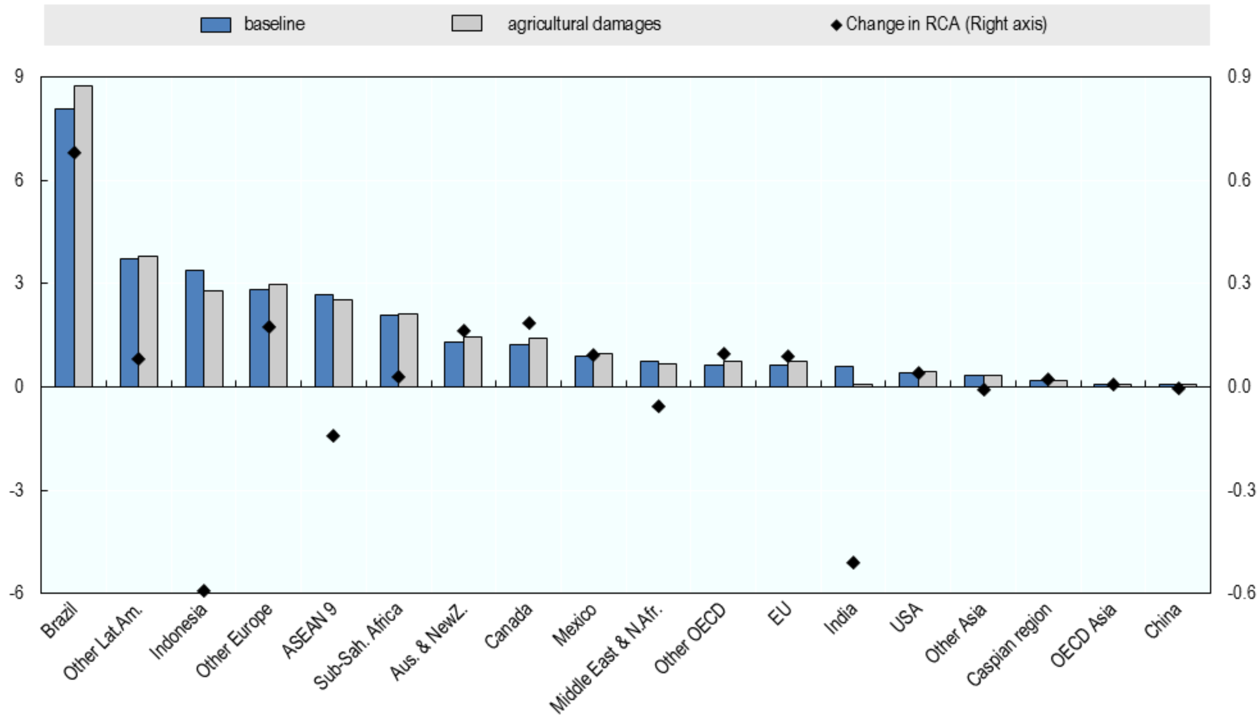
The macroeconomic consequences from considering agricultural impacts only are logically more modest than those of the full set of market damages. In terms of yield shocks, the largest losses are projected to be in Brazil and the Asian regions, especially India (cf. x-axis in Figure 11). Especially in Asia and Africa, the yield losses translate into significant reductions in GDP (y-axis in Figure 11). These results are fairly similar to the macroeconomic consequences of the full set of market damages, as discussed in Section 3.2. In particular, macroeconomic consequences are only very loosely related to the yield shocks imposed on the regional economies.

4.2.1 Revealed Comparative Advantage (RCA) in food products

Figure 12 shows the change in Revealed Comparative Advantage (RCA) for the baseline and the agricultural damages scenarios. It also shows the change in RCA between the two scenarios (diamonds in the figure). This figure shows first of all which regions have a strong specialisation and comparative advantage in food products. Brazil has the highest comparative advantage in both scenarios. A group of other regions, including the Other Latin America region, Indonesia, the Other Europe region, the ASEAN 9 region and Sub-Saharan Africa also have high comparative advantage in food products. Regions with smaller comparative advantage include Australia and New Zealand, Canada, Mexico, Middle East and North Africa, the EU, India and Other OECD countries. Finally some regions, namely the USA, other OECD and non-OECD Asian regions, China and the Caspian regions, do not specialise in trade of food products.

This distribution of comparative advantage is largely unchanged by climate change damages to the agricultural sector. However, climate change damages lead to changes in RCA for several regions and for some of the most specialised in the sector. Brazil remains the country with highest RCA and actually increases its comparative advantage with the highest increase among all regions. Smaller increases also take place in most other regions, and particularly in Europe, Australia and New Zealand and in North America. The South and South East Asia region is most damaged in its comparative advantage, especially Indonesia and India. The Middle East and North Africa region also loses comparative advantage in food products.

Figure 12. RCA levels and changes due to agricultural damages



Source: OECD ENV-Linkages model.

Changes in crop yields due to climate change are one of the drivers for these changes in comparative advantage. However, as all sectors and regions are linked with each other, a complex set of interactions and endogenous changes is triggered by the yield shocks, leading to adjustments in all sectors of all economies. Considering the correlation between RCA and crop yield changes, as illustrated in Figure 13, panel A, it is clear that crop yield changes alone cannot explain the changes in RCA. For instance, although Brazil and Indonesia have a similar loss in crop yields, Brazil gains in competitiveness, while Indonesia loses part of its competitiveness.

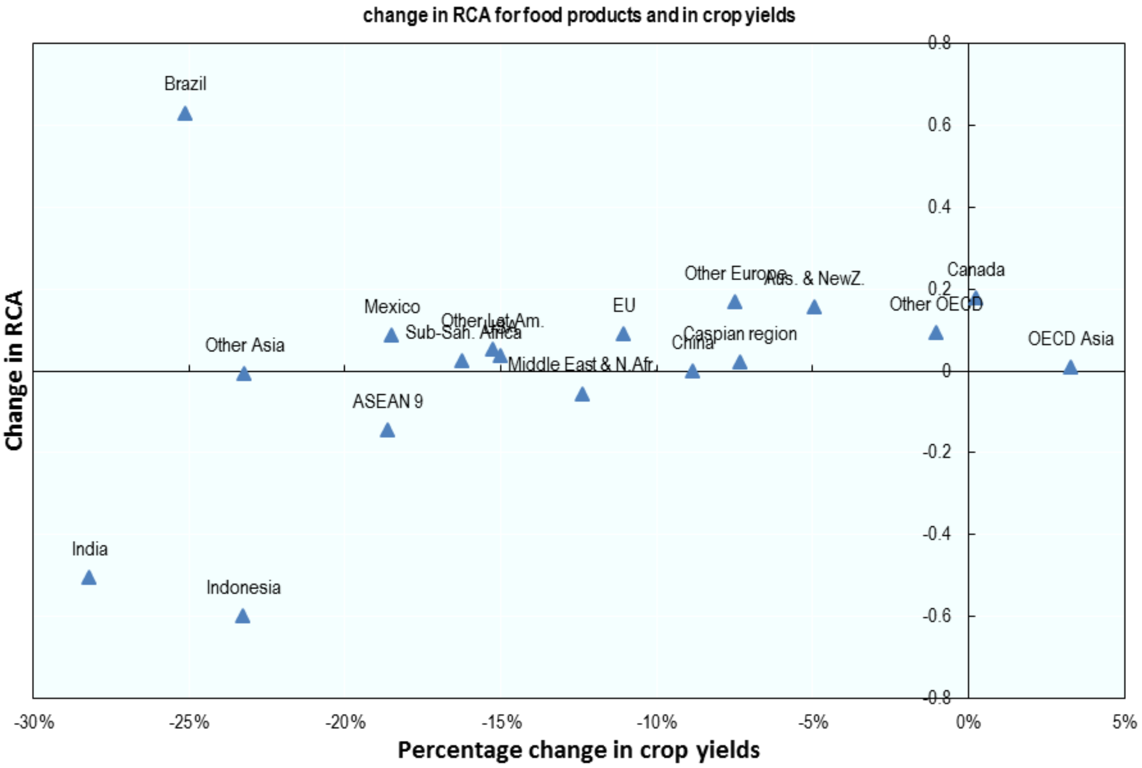
Panel B related the changes in RCAs to changes in the prices and volumes of exports. Those countries that have the largest increase in export prices see the largest drop in export volumes. As expected, the combined effect of these, i.e. changes in food export revenues, does show a clear link with the change in RCA: for those countries where the negative volume effect dominates, the RCA goes down, while for those where the volume effect is positive, or where the price effect dominates, the change in RCA is positive. But at the level of individual regions, more complex interactions play a role, and the regional changes in RCAs and export revenues cannot be fully explained at this aggregation level.

In order to better understand the interaction between trade flow changes, RCAs and competitiveness, it is therefore necessary to look more specifically at trade markets and competition amongst regions for a specific market. This is done in the next section.

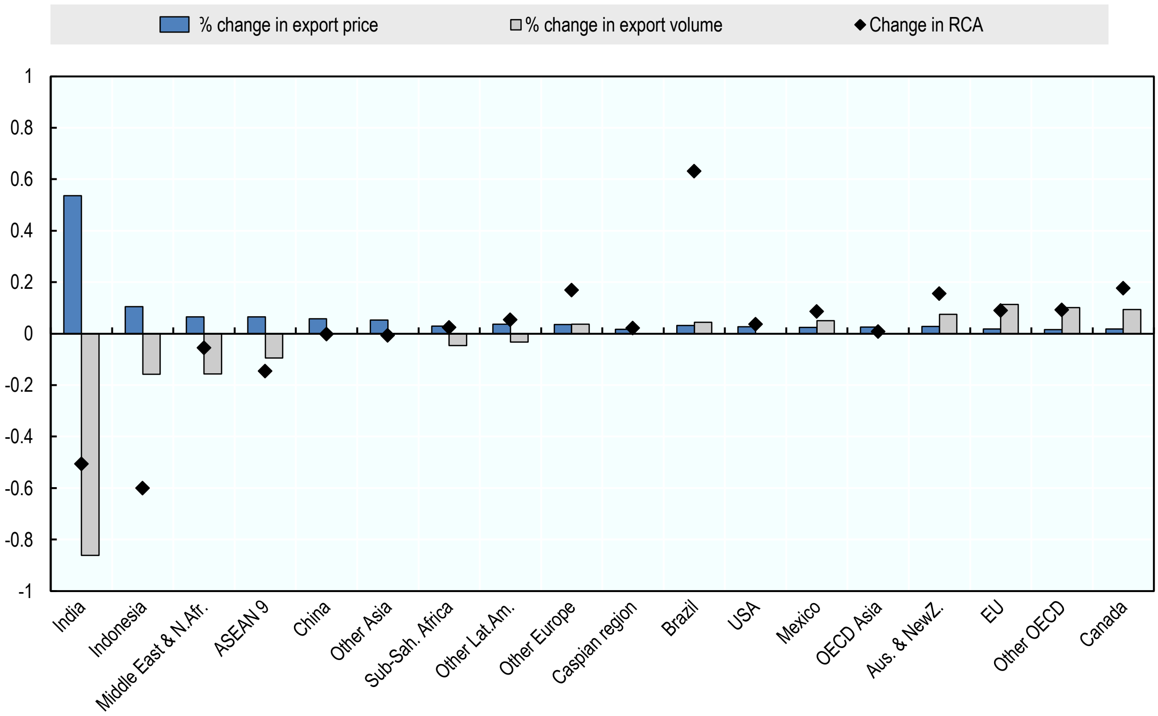
Figure 13. Changes in RCAs for food products and agricultural damages

Panel A. Changes in RCAs and crop yields

(Percentage change in 2060 w.r.t. no-damage baseline)



Panel B. Changes in RCAs and export prices and volumes



Source: OECD ENV-Linkages model.

4.2.2 A deeper look at RCAs: food exports to the EU

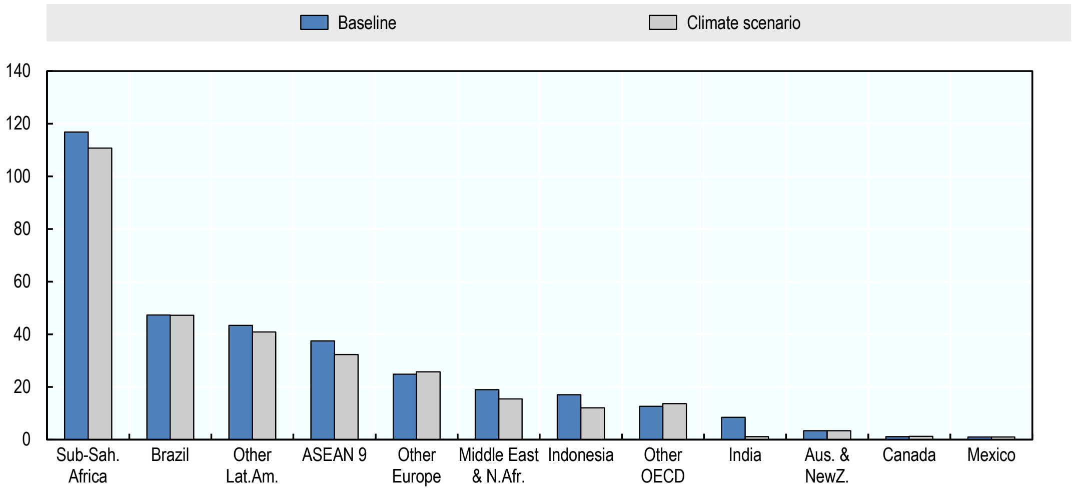
Given that many complex linkages between the trade flows of regions exist, and there are multiple drivers of trade changes, the overall changes in RCA do not say much. Rather, in order to shed further light on the linkages between GDP losses, changes in trade flows and comparative advantage, one must dive deeper into the model and focus on changes in more specific trade flows. Therefore, this subsection looks at the exports of food products (i.e. not raw agricultural commodities, but the output of the food industry) to the EU, and tries to shed light on the mechanisms at work. This specific case is chosen because Europe is one of the main importers and its main suppliers are the regions with large changes in RCA.

Figure 14, panel A presents the projected size of exports of food products to the EU by region of origin. The most important trading partner is projected to be Sub-Saharan Africa: up from 13% in 2010 (not shown in the figure), to a large extent at the expense of imports from other OECD countries. Brazil and to a lesser extent other Latin American countries roughly maintain their large shares in the coming decades. Climate change will have a small negative impact on overall food product imports in the EU, and hence for most countries exports to the EU will be reduced compared to the baseline (but not compared to 2010). Given the relatively small macroeconomic consequences of agricultural impacts from climate change on Europe, total imports to the EU hardly change; changes in exports of specific regions to the EU are therefore driven primarily by changes in the region's comparative advantage.

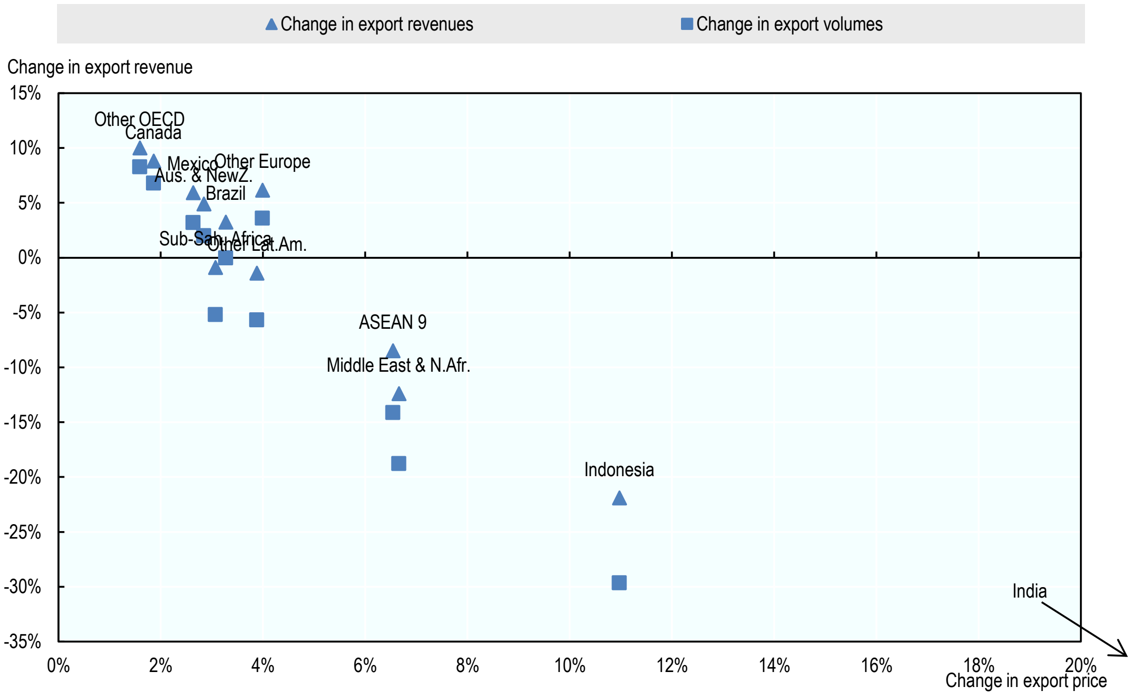
Panel B dives deeper into these changes in export flows. It portrays how changes in export prices (or more precisely, the prices that EU must pay for imports from this region) drive a wedge between the changes in export volumes and values (export revenues). Panel A already shows that climate damages to agriculture almost completely wipe out exports of food from India to the EU. Therefore, the percentage changes in exports are extremely large and not presented in panel B. The general picture that emerges from panel B is that the stronger the increase in regional prices, not least related to increases in exchange rates, the bigger the reduction in export volumes. And as it is *relative* comparative advantage that matters, those regions whose export price levels change least can gain in terms of export volumes. The second clear trend is that the export volume effect clearly dominates the price effect: those regions that see their export volumes decline also see a reduction in export revenues. Putting both mechanisms together implies that stronger price increases imply lower revenues and larger wedges between revenues and volumes.

Figure 14. Change in food exports to the EU in the agricultural damages scenario

Panel A. Volumes of exports of food products to the EU by region of origin
(Percentage change in 2060 w.r.t. no-damage baseline)



Panel B. Changes in volume and value of exports of food products to the EU

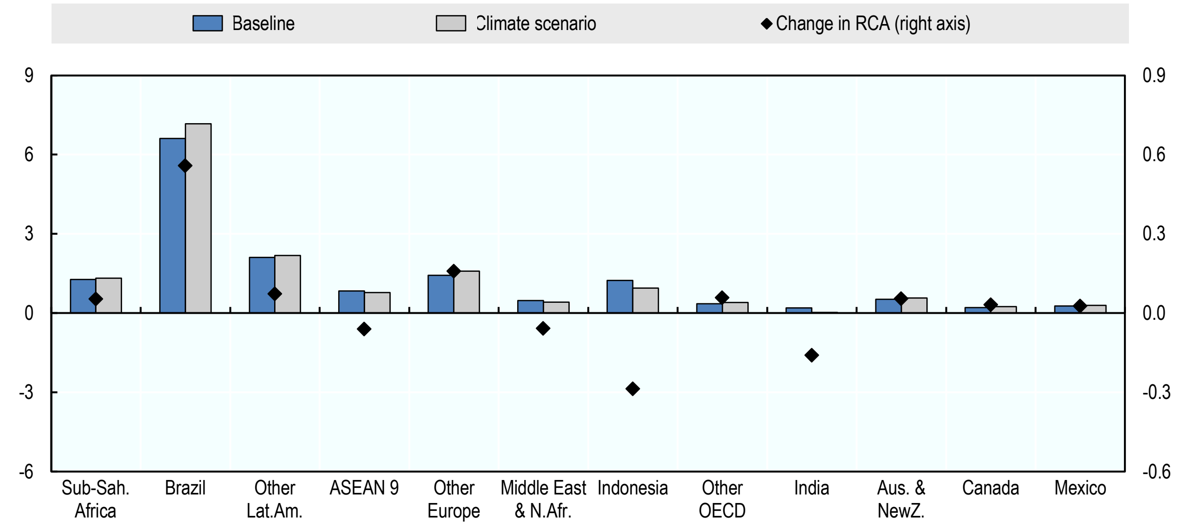


Note: In panel B, the percentage changes in India are too large to be meaningfully shown on the graph.
Source: OECD ENV-Linkages model.

The changes in regional comparative advantage are shown in Figure 15, which shows the projected RCA for exports to the EU (i.e. not based on global exports like above, but specifically for exports to the EU only). From comparing Figure 15 to Figure 12 it is clear that the change in RCA for exports to the EU closely resembles the change in the global RCA. It is the same set of countries which are projected to have the strongest change in their RCA, and strong reductions in RCA correlates with strong macroeconomic losses in these countries.

Figure 15. Levels and change in RCA of food exports to the EU in the agricultural damages scenario

(Percentage change in 2060 w.r.t. no-damage baseline)



Source: OECD ENV-Linkages model.

For Brazil, food products are projected to make up almost half of total exports to the EU, according to the baseline projection for 2060. Hence, Brazil's RCA is very high, and it increases further in the climate scenario (Figure 15), not because it will export more to the EU, but rather because the other trading partners will export less (Figure 14). Furthermore, as the domestic market in Brazil is more diversified than that of the other major trading partners of the EU: agriculture is projected to make up a relatively smaller share of overall output of the Brazilian economy. As a consequence, the macroeconomic consequences are smaller in Brazil than in the other regions, despite very similar yield shocks (cf. Box 2).

By contrast, a country like Indonesia, which has relatively smaller yield shocks but given the stronger dependency on agriculture, larger macroeconomic consequences, is projected to see its exports to the EU decline. The price that the EU for food imports increases substantially for imports from Indonesia and e.g. India and the Middle Eastern countries. This implies a shift of competitive position for exporting to the EU from counties like Indonesia towards countries like Brazil.

This case study is an illustration of some of the specific effects that drive changes in trade in the different regions. The numerous interactions that exist between regions and sectors make it impossible to establish a rule of thumb that shows for instance that crop yield decrease will lead to a decrease in competitiveness. As illustrated, there may be an increase in competitiveness if other competitors for a certain market are more severely damaged or decide to specialise in the production of other goods. This highlights the need for each region to understand the direct impacts of climate change on their sectoral production and on their trade flows, but also the possible impacts of climate change on regions they are competing with for specific markets. This will help maintain comparative advantage, if possible, and decisions regarding what goods to specialise in the future.

5 TRADE AS AN ECONOMIC MECHANISM TO ADAPT TO CLIMATE CHANGE

Future societies will have to adapt to climate change damages, especially in the sectors and regions that are most affected. Implementing adaptation policies and investing in adaptation technologies and infrastructures will certainly reduce climate change costs. However, there will also be a large role for market-driven adaptation. As production in certain sectors and regions becomes more costly, economies will adapt through changing in production patterns, sectoral specialisation and trade patterns. In other words, some resources will be reallocated across sectors in order to alleviate the burden in other sectors.

To the extent trade between countries will shift the allocation of resources across countries it could also been considered as an "adaptation mechanism" to climate change. The simulation results presented in the previous sections are based on assumptions of full market adaptation. For what regards trade, this means that each region can adapt to the changes in production and prices due to climate change by modifying their imports and exports.[18] For instance, if agricultural yields drastically decrease due to climate change for a certain crop, the gap in domestic production can be replaced with imports from abroad. The decision whether to import more will also depend on other factors, such as the changes in import and export prices, the changes in domestic prices, and the possibilities to substitute with other goods.

To further understand the role of trade as a component of adaptation, this section presents a preliminary analysis of an alternative counterfactual scenario in which regional trade patterns are prevented from adjusting to the climate shock. This "*damages without trade flexibility*" scenario is designed so as to reflect that the trade structure is the same as in the economic baseline without climate change.[19] In such a scenario, regions cannot modify their trade specialisation to adapt to the regional production and price changes taking place due to climate change. This is meant only as a theoretical exercise, which does not reflect specific adaptation or trade policies. Assessing the role of specific trade or trade-related policies would require a much more detailed analysis and is outside the scope of this report.

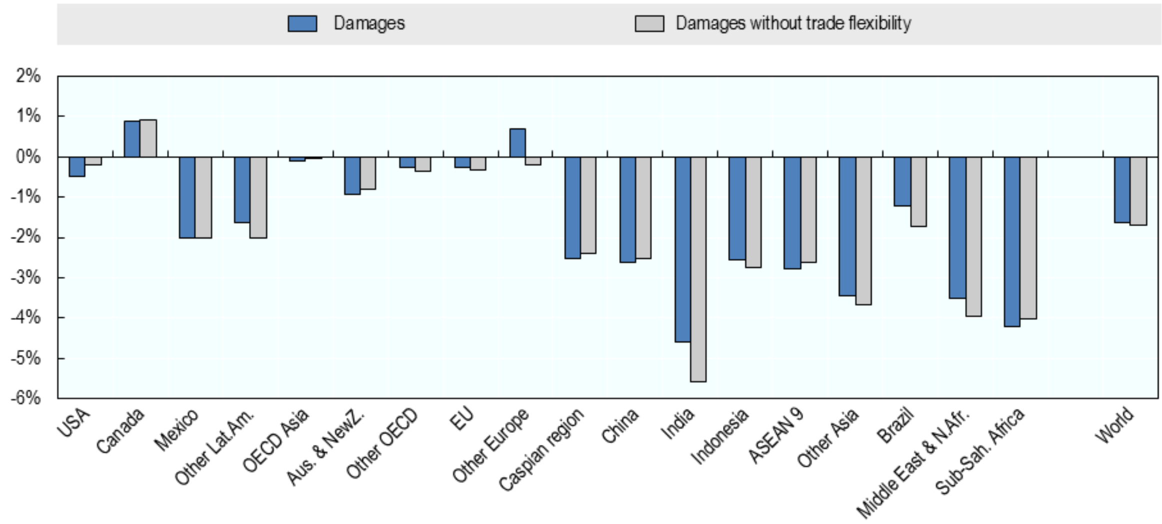
Figure 16 presents a comparison of real GDP by region between the climate damages scenarios with and without trade flexibility in 2060, both expressed as percentage change of the GDP in the baseline without climate damages. At global level, the lack of trade flexibility leads to higher costs in terms of reductions to GDP.

18 Changes in trade flows are still restricted by current account balance constraints (see Section 2).

19 For this preliminary analysis, import-to-production ratios and import shares across countries are assumed to be the same than in the baseline without climate feedbacks, but the volume of imports and trade flows themselves will adjust to take into account changes in income resulting from climate damages. In order to reproduce the trade structure of the baseline with no climate impacts this "damages without trade flexibility" scenario will assume that the parameters driving these import shares will adjust. Alternative ways of removing trade flexibility have been tested, such as changing the responsiveness of trade flows to changes in relative prices. The results of these alternative scenarios are similar to those presented here.

Figure 16. Changes in real GDP in 2060 in the climate damages scenario with and without trade flexibility – preliminary analysis

(Percentage change in GDP expressed in 2005 ppp w.r.t. no-damage baseline)



Note: This analysis is still preliminary, and the best specification to reflect a scenario without trade flexibility is to be determined for the final report.

Source: OECD ENV-Linkages model.

While this reduction is moderate at global level, there are strong differences amongst regions. Trade restrictions do not lead to a reduction of GDP in all regions relative to the case without restrictions (for example in Australia and New-Zealand). There are differences both in the direction and size of the effects of limiting trade adjustments.

According to the modelling results, India is particularly affected by the lack of trade flexibility, with GDP projected to decrease 5.5% by 2060 in the absence of trade flexibility, while in the scenario without trade restrictions the economic losses due to climate change are projected be 4.5% of GDP. In the climate damages scenarios agricultural yields in India are strongly affected. The model results suggest that to compensate these losses India will adapt its trade pattern mostly by increasing its import of food products, textiles and chemicals products (e.g. fertilizer). When market adaptation through trade is restricted, the economic costs of climate change are then larger for India because now it cannot compensate the losses in yields by importing food and other products as much as in the scenario without trade restrictions.

Indonesia is also an interesting case. In the scenario of climate damages with flexible trade patterns, Indonesia can specialise more in exporting textiles (as one of the major other textiles exporters, Indonesia, is more severely hit by climate change). Thus, despite strong domestic costs of climate change, its GDP loss is substantially smaller than that of India. But when the trade flexibility is removed, these climate-induced export opportunities disappear, and Indonesia is worse off.

In many regions, climate damages put pressure on the trade balance, and the deficit increases with climate impacts, at least when trade patterns can adjust flexibly. Removing trade flexibility then acts as a prevention mechanism against these deficits, and actually implies smaller GDP losses. The reasoning here is that with flexible trade patterns, these regions lose some of their export markets; they are better off in the hypothetical counterfactual where their export shares are artificially maintained at baseline levels. For some other regions, such as the ASEAN9 region and Sub-Saharan Africa, this positive trade balance effect outweighs the negative specialisation effects of removing trade flexibility, and hence they are better off without trade flexibility.

These effects depend crucially on the exact specification of the scenario, and on how the trade flexibility is limited. To what extent should trade deficits be fixed, or remain flexible? How to disentangle the effects of fixing imports from fixing exports in a global model where trade flows need to balance globally? These and other specification questions require further analysis, and will be pursued in the final report.[20]

6 CONCLUDING REMARKS

Providing a plausible projection of bilateral trade flows across many world regions for decades into the future is a daunting task, and then overlaying that with information on the economic consequences of climate change further complicates matters. The uncertainties surrounding these projections are large. Will Brazil by the middle of the century really be able to gain competitive advantage over Indonesia in exporting food to the EU? No-one knows. But this paper does not try to predict future trade patterns. Rather, it limits itself to presenting one plausible scenario of future developments, to shed light on the mechanisms at work in explaining how climate change will affect trade. More robust quantitative insights require more elaborate modelling analysis, using multiple scenarios on the major modelling assumptions, and ideally comparing different models. That is beyond the reach of this paper. Nonetheless, a number of general insights emerge that are worth highlighting.

First, international trade flows are projected to increase substantially in the coming decades, with increased focus on trade outside the OECD region. But climate damages will put negative pressure on the economies of almost all regions, and trade flows are smaller when considering climate damages than in the naïve baseline that ignores feedbacks from climate change on the economy. These effects are especially strong in Africa and Asia, where high economic growth rates combine with increased trade dependency and large damages from climate change. In terms of economic sectors, the impacts on agriculture are relatively strong, and as agricultural goods and food products are heavily internationally traded, changes in agricultural trade flows are projected to be stronger than changes in trade flows for most other commodities.

Secondly, in the most affected countries exports decline more than imports and GDP. In contrast, producers in the least affected countries can improve their competitive position on both domestic and export markets. "Least affected" in this case is a relative term: what matters more are the domestic damages compared with those of the main trading partners, rather than absolute damage levels. Despite being negatively affected by climate damages, a region may increase its competitiveness if other competitors for a certain market are more severely damaged or decide to specialise in the production of other goods.

Thirdly, the mechanisms driving changes in trade patterns are very complex, with mutually reinforcing and dampening effects. Generally, countries that have larger domestic markets and more diversified trade patterns can absorb climate shocks better than countries that are more specialised. Comparative advantage

[20] Delegates are very welcome to provide suggestions on this topic.

tends to decline in countries where climate damages lead to relatively large reductions in export volumes, while those regions whose export price levels change least can gain in terms of export volumes.

It is impossible to establish more robust rules of thumb on the competitiveness effects of climate change, and at the regional level, changes in Revealed Comparative Advantage (RCA) are not directly linked to specific changes in trade patterns. Each region will need to understand not only the impacts of climate change on their domestic sectoral production and trade flows, but also the projected impacts of climate change on regions they are competing with on specific markets. This will help maintaining comparative advantage, if possible, and deciding in what goods to specialise in the future.

Fourthly, adjusting trade patterns is a useful mechanism to minimise the costs of climate change. Without trade flexibility, the global costs of climate change are projected to be higher, especially in some of the regions which are most severely affected by climate damages. The analysis on the implications of removing trade flexibility as presented in this draft paper are preliminary, however, and warrants further work to identify the most appropriate modelling assumptions and disentangle the consequences further to allow for clearer insights.

In this draft report, it was impossible to include any direct impacts of climate change on international trade. However, this could be pursued further if reliable information becomes available on e.g. the change in overall costs from climate impacts on international sea, air and land transport, or more specifically on the changes in transportation costs from opening up of the Arctic shipping route. Especially the latter would ideally be pursued in close collaboration with the International Trasnport Forum (ITF).

While an analysis of the trade policy response to climate change is beyond the scope of this paper, trade agreements and trade policies can be used to alleviate some of the major negative consequences and potentially reap multiple benefits. For instance Chateau et al. (2015) show that a "partial multilateral scenario" will benefit all countries, but especially the same less-developed economies which are most threatened by climate change. The main policy recommendation from this paper is therefore that climate policies and trade policies could be aligned in order to offset some of the worst climate damages and alleviate the burden on the most vulnerable economies.

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ANNEX I. DESCRIPTION OF THE ENV-LINKAGES MODELLING TOOL

The OECD's in-house dynamic computable general equilibrium (CGE) model - ENV-Linkages - is used as the basis for the assessment of the economic consequences of climate impacts until 2060. The advantage of using a CGE framework to model climate impacts is that the sectoral details of the model can be exploited. Contrary to aggregated IAMs, where monetised impacts are directly subtracted from GDP, in a CGE model the various types of climate damages can be modelled as directly linked to the relevant sectors and economic activities.

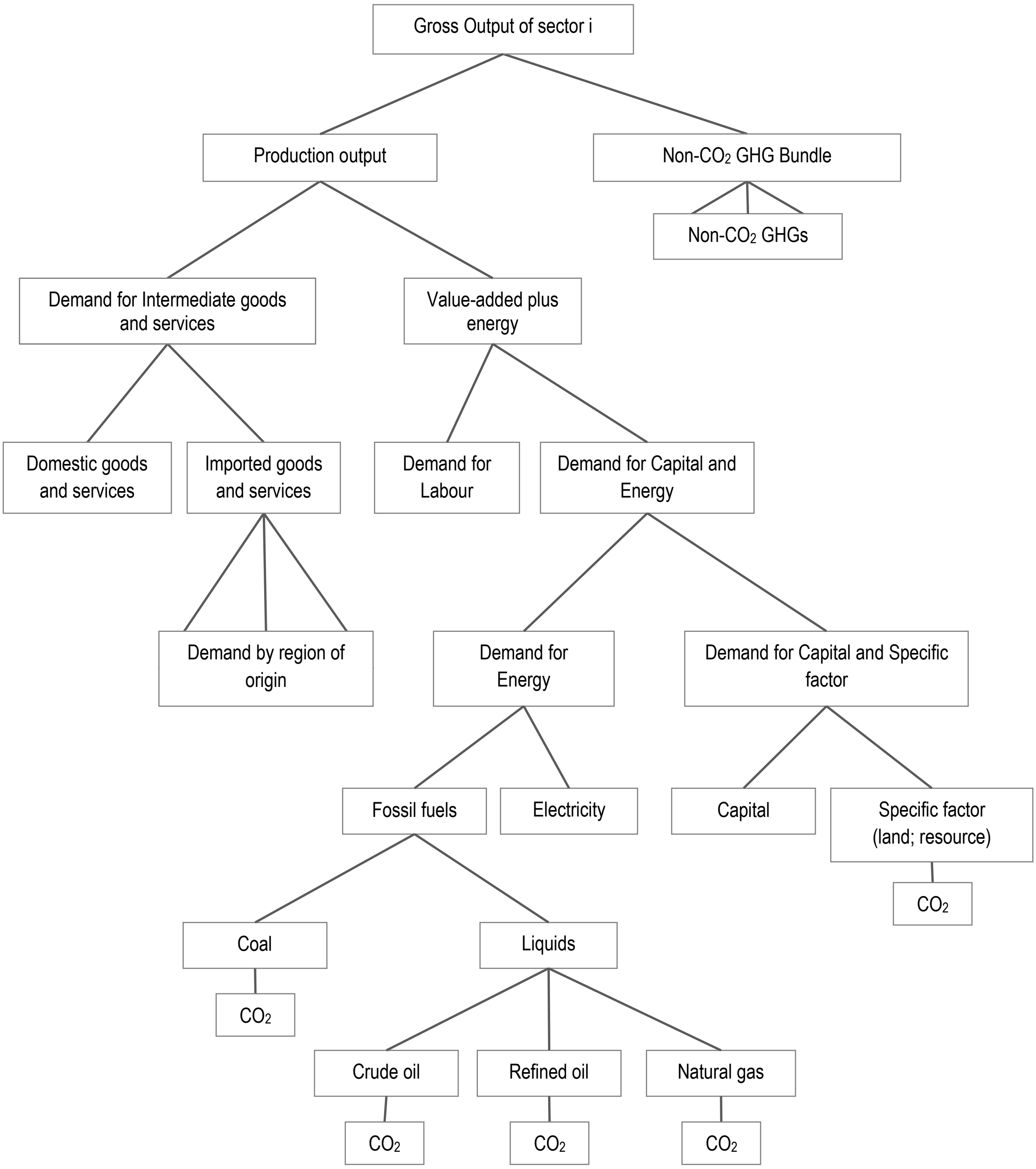
ENV-Linkages is a multi-sectoral, multi-regional model that links economic activities to energy and environmental issues; Chateau *et al*. (2014) provide a description of the model. The model is calibrated for the period 2013 - 2060 using the macroeconomic trends of the baseline scenario of the OECD's Economic Outlook (2014a). The ENV-Linkages model is the successor to the OECD GREEN model for environmental studies (Burniaux, *et al.* 1992).

Production in ENV-Linkages is assumed to operate under cost minimisation with perfect markets and constant return to scale technology. The production technology is specified as nested Constant Elasticity of Substitution (CES) production functions in a branching hierarchy (cf. Figure AI.1). This structure is replicated for each output, while the parameterisation of the CES functions may differ across sectors. The nesting of the production function for the agricultural sectors is further re-arranged to reflect substitution between intensification (e.g. more fertiliser use) and extensification (more land use) of crop production; or between intensive and extensive livestock production. The structure of electricity production assumes that a representative electricity producer maximizes its profit by using the different available technologies to generate electricity using a CES specification with a large degree of substitution. The structure of non-fossil electricity technologies is similar to that of other sectors, except for a top nest combining a sector-specific resource with a sub-nest of all other inputs. This specification acts as a capacity constraint on the supply of the electricity technologies.

The model adopts a putty/semi-putty technology specification, where substitution possibilities among factors are assumed to be higher with new vintage capital than with old vintage capital. In the short run this ensures inertia in the economic system, with limited possibilities to substitute away from more expensive inputs, but in the longer run this implies relatively smooth adjustment of quantities to price changes. Capital accumulation is modelled as in the traditional Solow/Swan neo-classical growth model.

The energy bundle is of particular interest for analysis of climate change issues. Energy is a composite of fossil fuels and electricity. In turn, fossil fuel is a composite of coal and a bundle of the "other fossil fuels". At the lowest nest, the composite "other fossil fuels" commodity consists of crude oil, refined oil products and natural gas. The value of the substitution elasticities are chosen as to imply a higher degree of substitution among the other fuels than with electricity and coal.

Figure AI.1. Production structure of a generic sector in ENV-Linkages[21]



Source: OECD ENV-Linkages model.

21 This generic structure does not apply to energy and agricultural sectors.

Household consumption demand is the result of static maximization behaviour which is formally implemented as an “Extended Linear Expenditure System”. A representative consumer in each region – who takes prices as given – optimally allocates disposal income among the full set of consumption commodities and savings. Saving is considered as a standard good in the utility function and does not rely on forward-looking behaviour by the consumer. The government in each region collects various kinds of taxes in order to finance government expenditures. Assuming fixed public savings (or deficits), the government budget is balanced through the adjustment of the income tax on consumer income. In each period, investment net-of-economic depreciation is equal to the sum of government savings, consumer savings and net capital flows from abroad.

International trade is based on a set of regional bilateral flows. The model adopts the Armington specification, assuming that domestic and imported products are not perfectly substitutable. Moreover, total imports are also imperfectly substitutable between regions of origin. Allocation of trade between partners then responds to relative prices at the equilibrium.

Market goods equilibria imply that, on the one side, the total production of any good or service is equal to the demand addressed to domestic producers plus exports; and, on the other side, the total demand is allocated between the demands (both final and intermediary) addressed to domestic producers and the import demand.

CO_2 emissions from combustion of energy are directly linked to the use of different fuels in production. Other greenhouse gas (GHG) emissions are linked to output in a way similar to Hyman *et al*. (2002). The following non-CO_2emission sources are considered: i) methane from rice cultivation, livestock production (enteric fermentation and manure management), fugitive methane emissions from coal mining, crude oil extraction, natural gas and services (landfills and water sewage); ii) nitrous oxide from crops (nitrogenous fertilizers), livestock (manure management), chemicals (non-combustion industrial processes) and services (landfills); iii) industrial gases (SF6, PFCs and HFCs) from chemicals industry (foams, adipic acid, solvents), aluminium, magnesium and semi-conductors production. Over time, there is, however, some relative decoupling of emissions from the underlying economic activity through autonomous technical progress, implying that emissions grow less rapidly than economic activity.

Emissions can be abated through three channels: (i) reductions in emission intensity of economic activity; (ii) changes in structure of the associated sectors away from the ‘dirty’ input to cleaner inputs, and (iii) changes in economic structure away from relatively emission-intensive sectors to cleaner sectors. The first channel, which is not available for emissions from combustion of fossil fuels, entails end-of-pipe measures that reduce emissions per unit of the relevant input. The second channel includes for instance substitution from fossil fuels to renewable in electricity production, or investing in more energy-efficient machinery (which is represented through higher capital inputs but lower energy inputs in production). An example of the third channel is a substitution from consumption of energy-intensive industrial goods to services. In the model, the choice between these three channels is endogenous and driven by the price on emissions.

ENV-Linkages is fully homogeneous in prices and only relative prices matter. All prices are expressed relative to the *numéraire* of the price system that is arbitrarily chosen as the index of OECD manufacturing exports prices. Each region runs a current account balance, which is fixed in terms of the *numéraire*. One important implication from this assumption in the context of this report is that real exchange rates immediately adjust to restore current account balance when countries start exporting/importing emission permits.

As ENV-Linkages is recursive-dynamic and does not incorporate forward-looking behaviour, price-induced changes in innovation patterns are not represented in the model. The model does, however, entail technological progress through an annual adjustment of the various productivity parameters in the model, including e.g. autonomous energy efficiency and labour productivity improvements. Furthermore, as production with new capital has a relatively large degree of flexibility in choice of inputs, existing technologies can diffuse to other firms. Thus, within the CGE framework, firms choose the least-cost combination of inputs, given the existing state of technology. The capital vintage structure also ensures that such flexibilities are large in the long run than in the short run.

The sectoral and regional aggregation of the model, as used in the analysis for this report, are given in Tables AI.1 and AI.2, respectively.

Table AI.1. Sectoral aggregation of ENV-Linkages

Agriculture	Manufacturing
Paddy Rice	Paper and paper products
Wheat and meslin	Chemicals
Other Grains	Non-metallic minerals
Vegetables and fruits	Iron and Steel
Sugar cane and sugar beet	Metals n.e.s.
Oil Seeds	Fabricated metal products
Plant Fibres	Food Products
Other Crops	Other manufacturing
Livestock	Motor vehicles
Forestry	Electronic Equipment
Fisheries	Textiles
Natural Resources and Energy	**Services**
Coal	Land Transport
Crude Oil	Air and Water Transport
Gas extraction and distribution	Construction
Other mining	Trade Other Services and Dwellings
Petroleum and coal products	Other Services (Government)
Electricity (7 technologies)	
Fossil-Fuel based Electricity; Combustible renewable and waste based Electricity; Nuclear Electricity; Hydro and Geothermal; Solar and Wind; Coal Electricity with CCS; Gas Electricity with CCS	

Table AI.2. Regional aggregation of ENV-Linkages

Macro regions	ENV-Linkages countries and regions
OECD America	Canada Chile Mexico United States
OECD Europe	EU large 4 (France, Germany, Italy, United Kingdom) Other OECD EU (other OECD EU countries) Other OECD (Iceland, Norway, Switzerland, Turkey, Israel)
OECD Pacific	Oceania (Australia, New Zealand) Japan Korea
Rest of Europe and Asia	China Non-OECD EU (non-OECD EU countries) Russia Caspian region Other Europe (non-OECD, non-EU European countries)
Latin America	Brazil Other Lat.Am. (other Latin-American countries)
Middle East & North Africa	Middle-East North Africa
South and South-East Asia	India Indonesia ASEAN9 (other ASEAN countries) Other Asia (other developing Asian countries)
Sub-Saharan Africa	South Africa Other Africa (other African countries)

ANNEX II. DETAILS ON THE EVOLUTION OF INTERNATIONAL TRADE IN THE NO-DAMAGE BASELINE PROJECTION

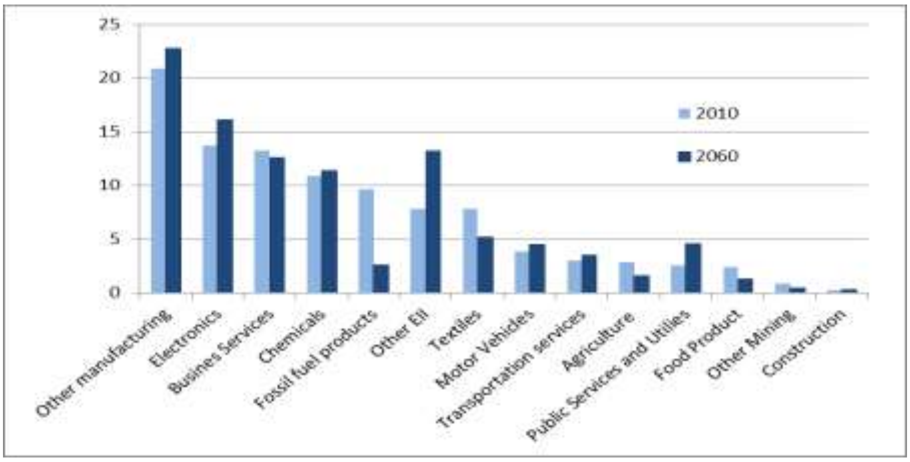
Trade specialisation patterns or the relative importance of different countries and regions in markets for each good and service markets will change over time, driven by the same four drivers of international trade, but more precisely by the differences across countries in relative productivity (or production costs) changes and by the convergence in consumption patterns.

II.1 Changes in consumption patterns

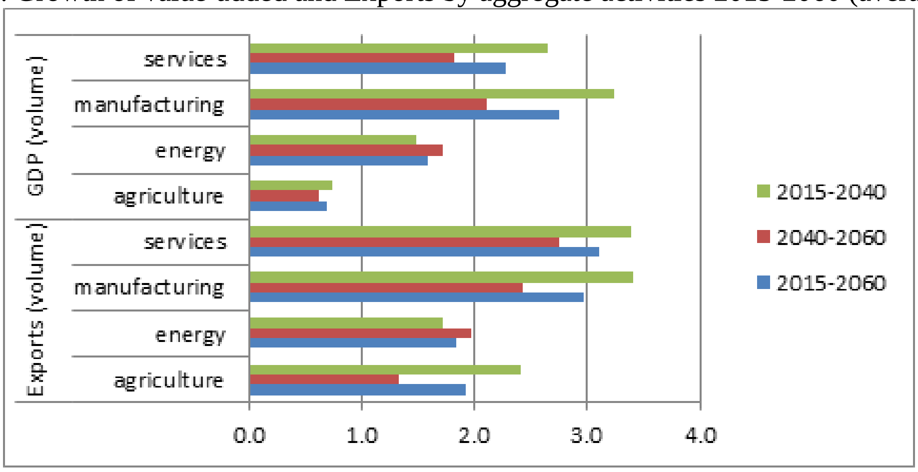
The baseline scenario for the world economy will project convergence in consumption patterns and this for two reasons. Firstly as standards of living are growing the consumption of all kind of services is increasing, as a percentage of total income, while the share of consumption of necessity goods is decreasing. These changes in consumption patterns are more pronounced in fast growing economy than in OECD countries where some levels of satiation would occur. Secondly, the projection also assumes that household's preferences themselves will converge towards OECD standards. As a result the composition of demand will change over time (Figure 6).

Figure AII.1. Changes in sectoral composition of world trade

Panel A. gross exports by aggregate industries as percentage of total exports)



Panel B. Growth of value-added and Exports by aggregate activities 2015-2060 (average rate)



Source: OECD ENV-Linkages model.

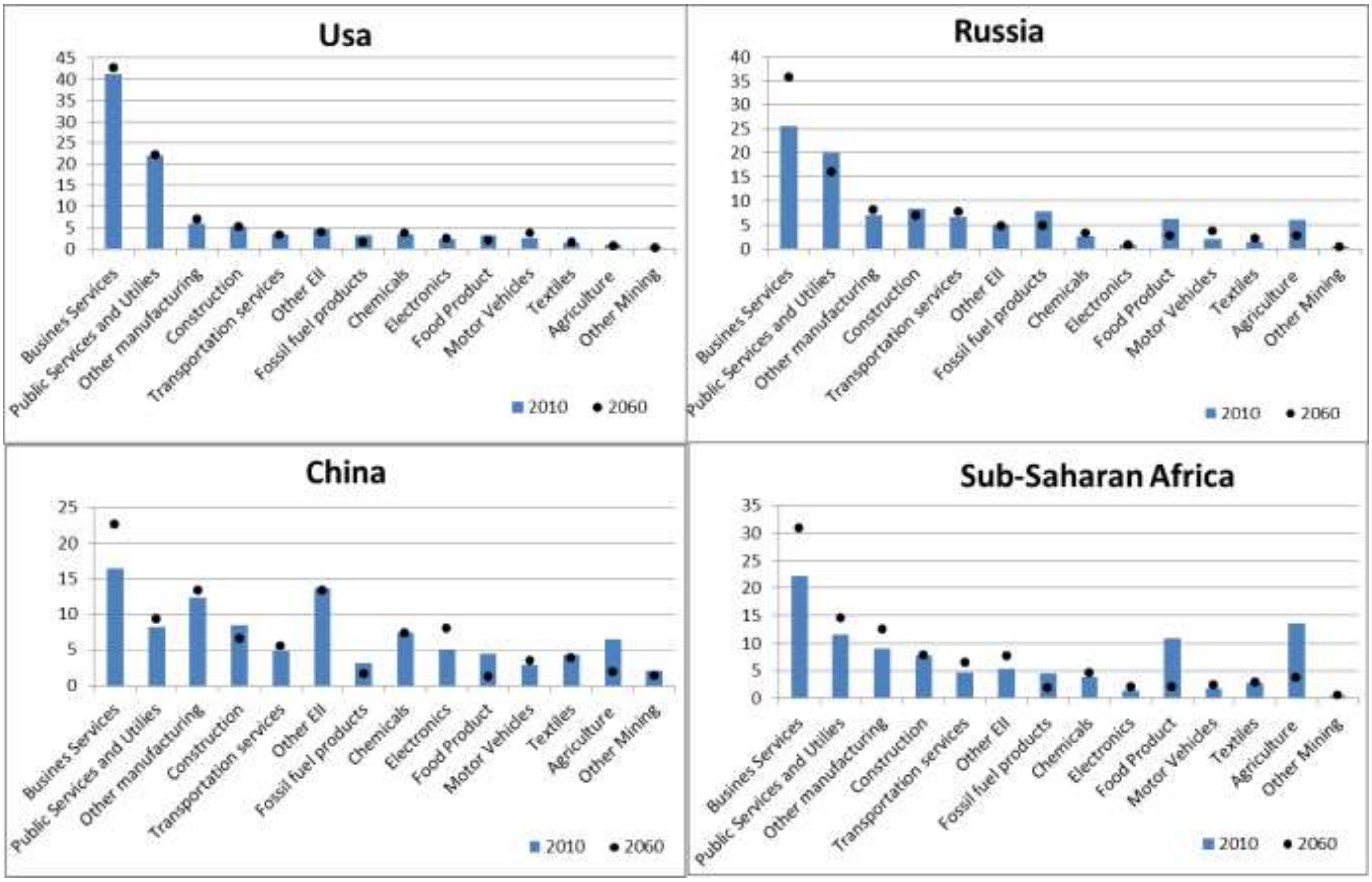
II.2 Changes in production patterns

A second force is that production structures also change over time: some sectors in some countries will take advantage of some comparative advantage, associated with the change in endowments of production factor inputs or in their efficiency use relative to other factors. This will explain that there will be that will not necessarily correspond to the changes in demand and then call for some changes in trade specialisation patterns.

Two kind of good deserve a closer examination. Energy and Agricultural goods, as they ultimately depend strictly on very unevenly distributed primary factors: natural resources and land factors. Notice also that a large part of the efficiency of these factors are also regional (extraction costs of fossil fuel are function of the quality of the land surface while land yields are function of the climate and geographical position).

Figure AII.2 Changes in consumption patterns, selected countries

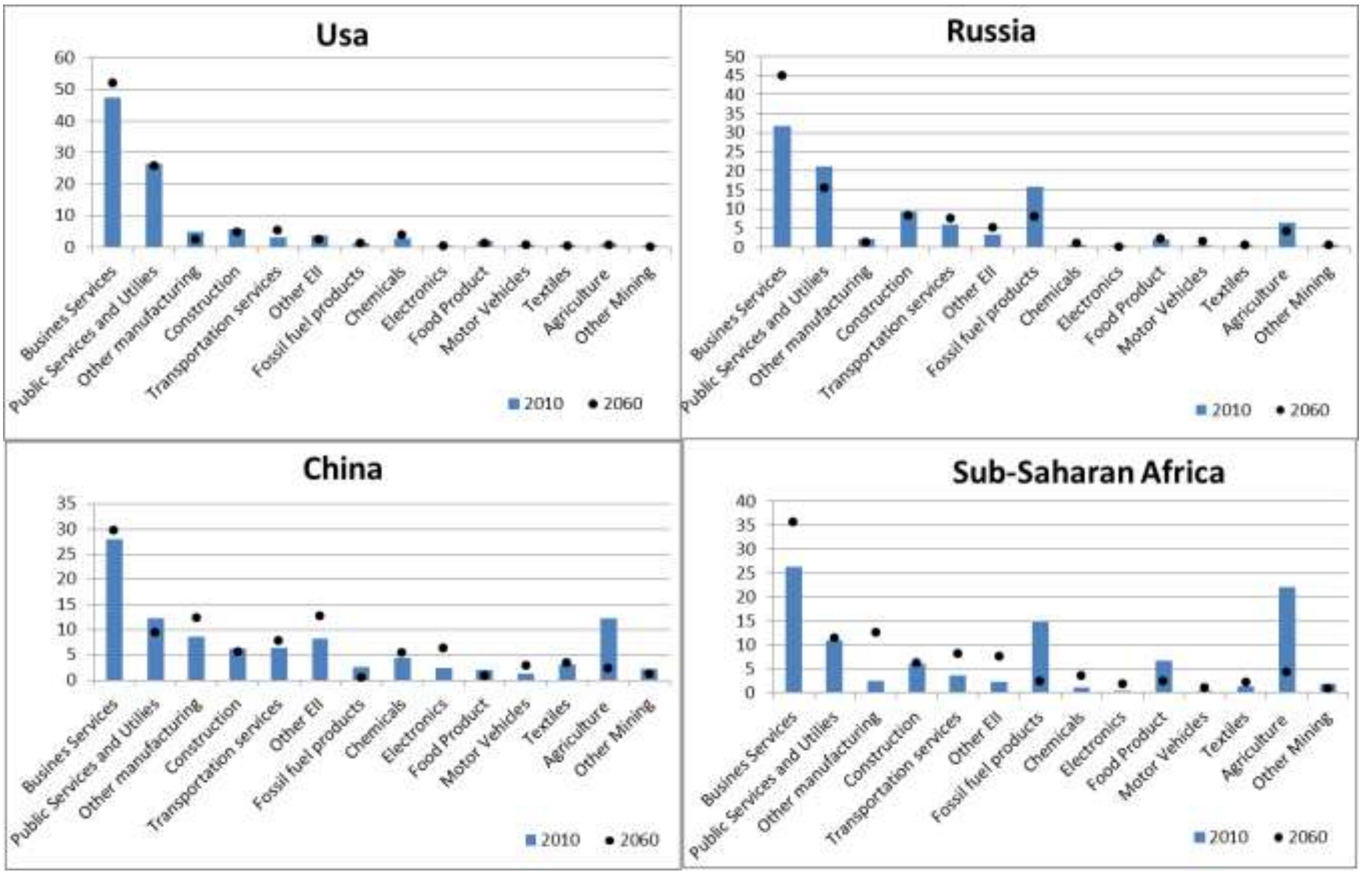
(Demand shares as percentage of total demand, 2010-2060)



Source: OECD ENV-Linkages model.

Figure AII.3 Changes in industrial structure, selected countries

(Value added shares in total GDP, 2010-2060)



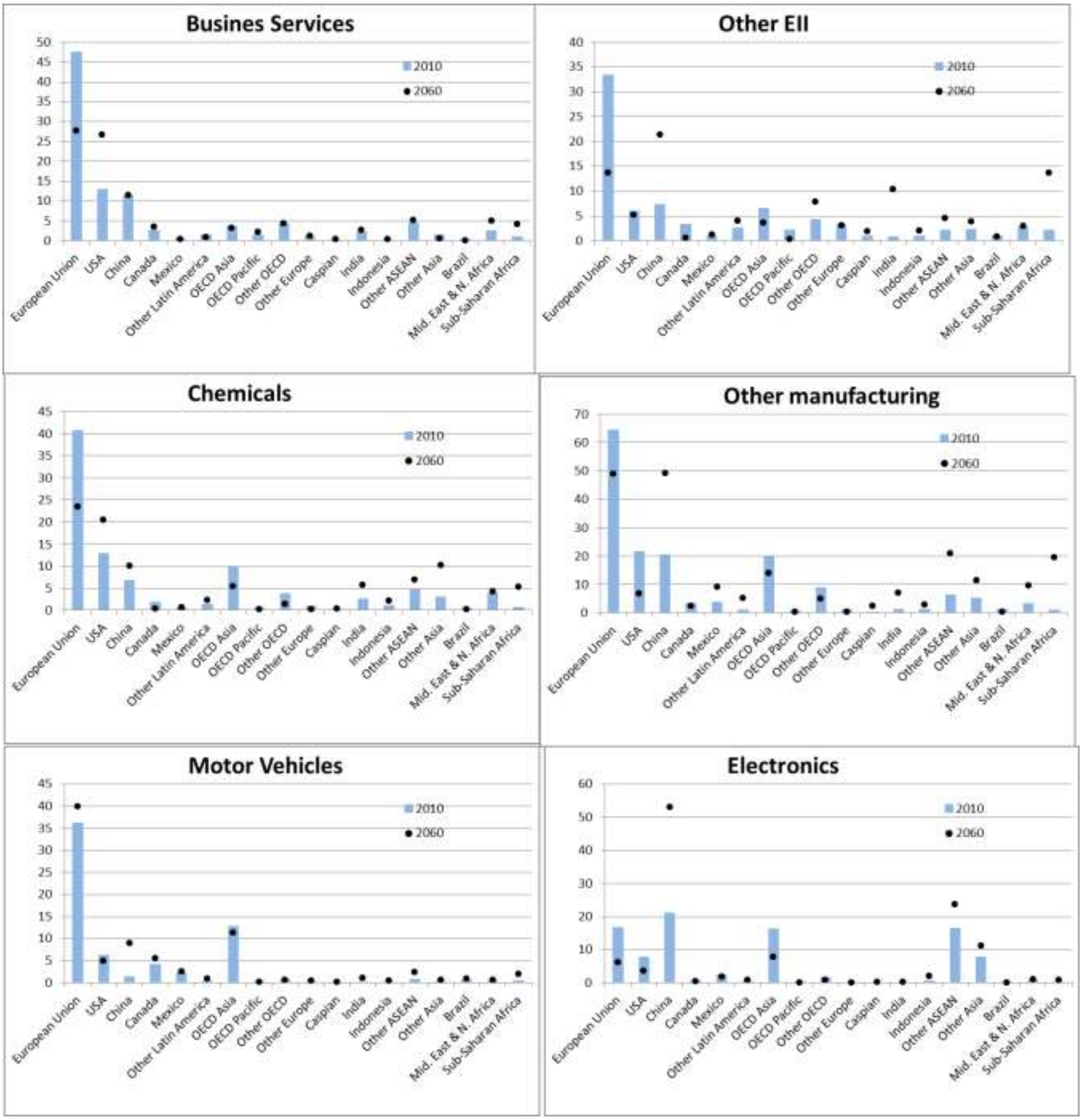
Source: OECD ENV-Linkages model.

II.3 Changes in trade specialisation

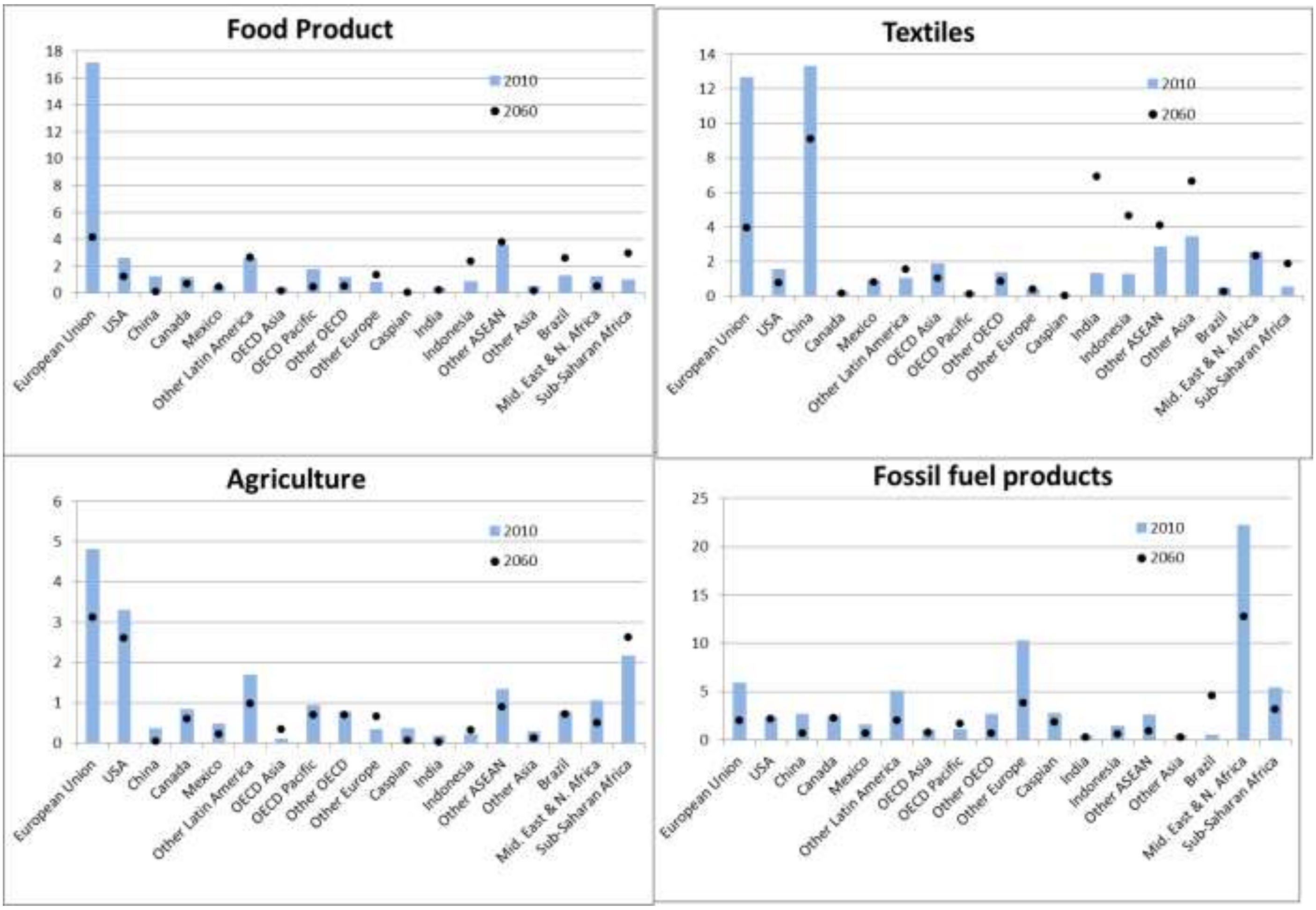
Figure AII.4. Changes in trade specialisation patterns in selected aggregate industries

(Trade shares as percentage of global trade, 2010-2060)

Panel A. Transformed Good and Services



Panel B. Raw Product and Transformed raw products



Source: OECD ENV-Linkages model.