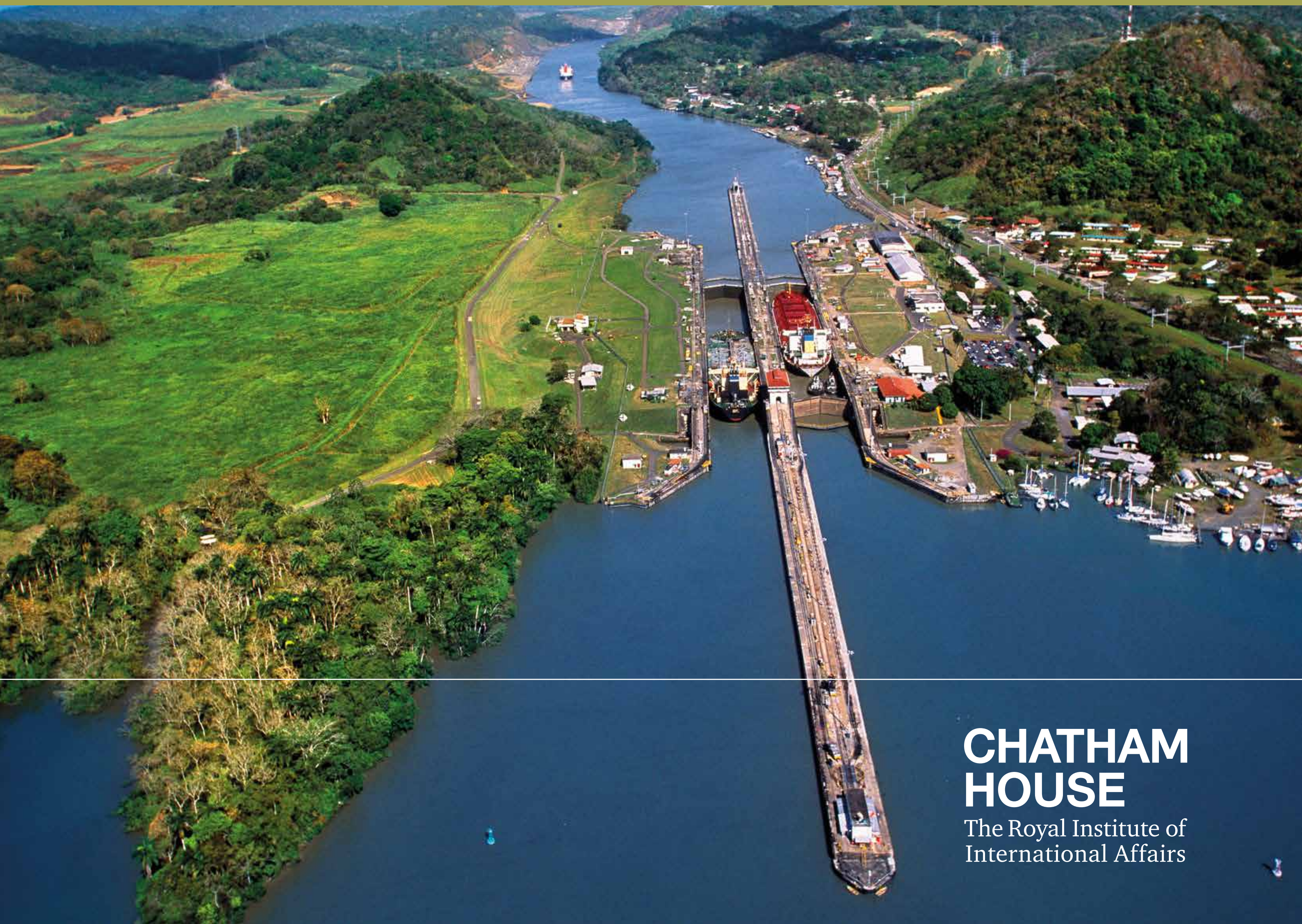
Chatham House Report

Rob Bailey and Laura Wellesley

Chokepoints and Vulnerabilities in Global Food Trade



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Rob Bailey and Laura Wellesley
Energy, Environment and Resources Department | June 2017

Chokepoints and Vulnerabilities in Global Food Trade

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Charity Registration No. 208223

ISBN 978 1 78413 230 9

A catalogue record for this title is available from the British Library.

Typeset by Soapbox, www.soapbox.co.uk

Cover image: Pedro Miguel locks, Panama Canal. Copyright © Gonzalo Azumendi/Getty Images

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Executive Summary

Global food security is underpinned by trade in a few crops and fertilizers. Just three crops – maize, wheat and rice – account for around 60 per cent of global food energy intake.[1] A fourth crop, soybean, is the world's largest source of animal protein feed, accounting for 65 per cent of global protein feed supply.[2] Each year, the world's transport system moves enough maize, wheat, rice and soybean to feed approximately 2.8 billion people.[3] Meanwhile, the 180 million tonnes of fertilizers applied to farmland annually play a vital role in helping us grow enough wheat, rice and maize to sustain our expanding populations.[4]

International trade in these commodities is growing, increasing pressure on a small number of 'chokepoints' – critical junctures on transport routes through which exceptional volumes of trade pass. Three principal kinds of chokepoint are critical to global food security: maritime corridors such as straits and canals; coastal infrastructure in major crop-exporting regions; and inland transport infrastructure in major crop-exporting regions.

A serious interruption at one or more of these chokepoints could conceivably lead to supply shortfalls and price spikes, with systemic consequences that could reach beyond food markets. More commonplace disruptions may not in themselves trigger crises, but can add to delays, spoilage and transport costs, constraining market responsiveness and contributing to higher prices and increased volatility.

The chokepoints on which global food security depends

This report offers a first-of-its-kind analysis of chokepoints in the global food system, combining trade data from the Chatham House Resource Trade Database (https://resourcetrade.earth) with a purpose-built model to map bilateral commodity flows on to trade routes. It identifies 14 chokepoints that are critical to global food security. These are indicated in Figure 1.

Among the maritime chokepoints, the Panama Canal and Strait of Malacca[5] see the most significant grain throughput due to their positions linking Western and Asian markets. Over one-quarter of global soybean exports transit the Strait of Malacca, primarily to meet animal feed demand in China and Southeast Asia. The Turkish Straits[6] are particularly critical for wheat – a fifth of global exports pass through them each year, largely from the Black Sea 'breadbasket' region.

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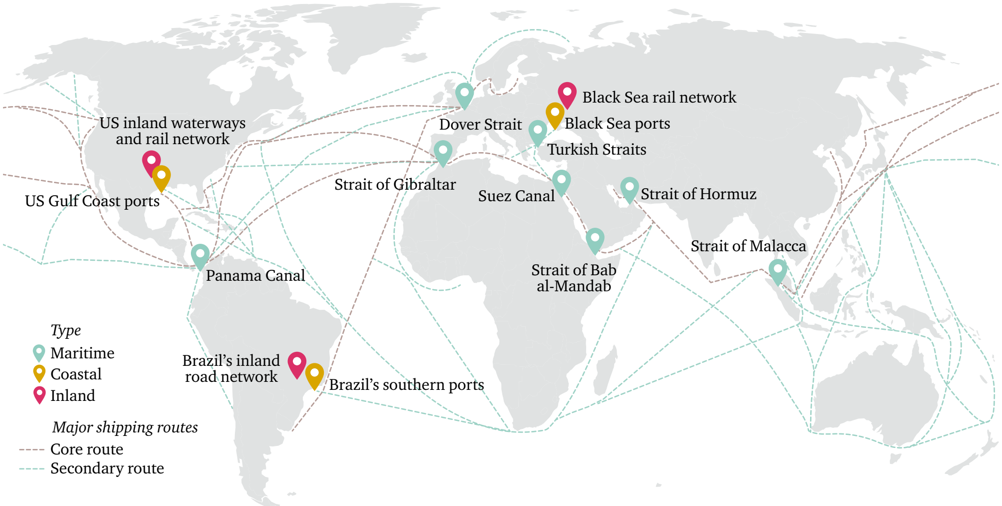
[1] Worldwatch Institute (2013), *Vital Signs: The Trends That Are Shaping Our Future,* Volume 20, Washington, DC: Worldwatch Institute.
[2] Worldwatch Institute (2016), 'Soybean Demand Continues to Drive Production', http://www.worldwatch.org/node/5442 (accessed 20 Apr. 2017).
[3] This assumes that all calories traded are available as food, and is based on the World Health Organization's recommended daily intake of 2,000 kilocalories per capita per day. Caloric equivalence factors for wheat, rice, soybean and maize were derived by Paul West and James Gerber at the University of Minnesota, and are based on UN Food and Agriculture Organization (FAO) (2001), *Food Balance Sheets: A Handbook,* Rome: FAO, http://www.fao.org/docrep/003/X9892E/X9892E00.HTM (accessed 3 May 2017).
[4] FAO (2016), *World fertilizer trends and outlook to 2019: Summary Report,* Rome: FAO, http://www.fao.org/3/a-i5627e.pdf (accessed 20 Apr. 2017).
[5] Which also includes the Singapore Strait.
[6] Consisting of the Bosphorus Stait and the Dardanelles.

Figure 1: Maritime, coastal and inland chokepoints and major shipping routes



Source: Shipping routes adapted from Rodrigue, J.-P., Comtois, C. and Slack, B. (2017), *The Geography of Transport Systems*, New York: Routledge, https://people.hofstra.edu/geotrans/.

The most important inland and coastal chokepoints lie in the US, Brazil and the Black Sea, which account for 53 per cent of global exports of wheat, rice, maize and soybean. Inland waterways carry about 60 per cent of US exports of the four crops (which account for 13 per cent of worldwide exports) to the sea, primarily to the Gulf Coast ports. In Brazil, four ports on the southeastern coastline are responsible for nearly a quarter of global soybean exports; these ports in turn depend on the roads linking them to the huge farms in the country's interior. Around 60 per cent of Russian and Ukrainian wheat exports (12 per cent of the global total, and growing fast) depend on rail to reach the Black Sea.

Chokepoint risk is increasing

These chokepoints are exposed to three broad categories of disruptive hazards. First there are weather and climate hazards, including storms or floods that may temporarily close chokepoints, and weather-related wear and tear of infrastructure that reduces its efficiency and makes it more vulnerable to extreme events. Second, security and conflict hazards may arise from war, political instability, piracy, organized crime and/or terrorism. The third category of hazards are institutional, such as a decision by authorities to close a chokepoint or restrict the passage of food (for example, by imposing export controls).

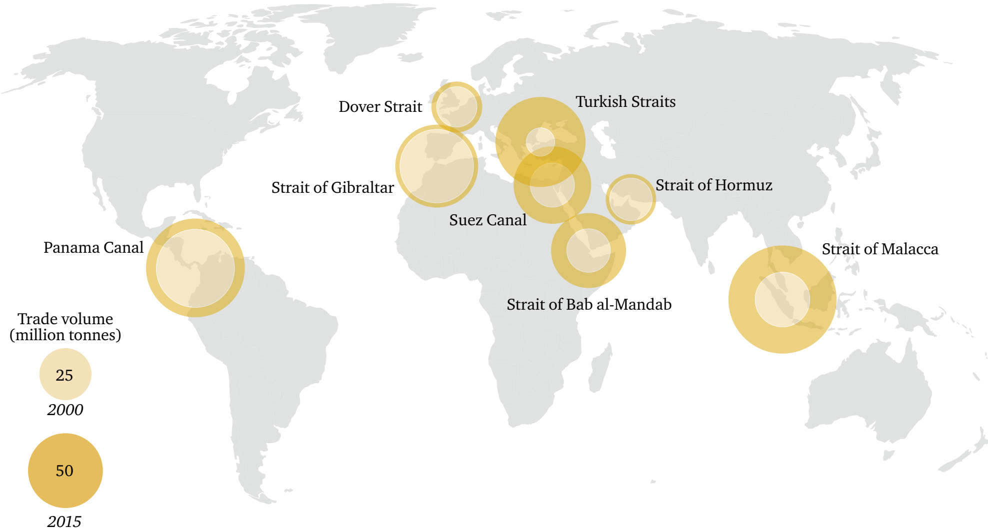
Minor disruptions are common. All but one of the chokepoints covered in this report has seen a closure or interruption of transit at least once in the past 15 years,[7] and the risk of a crisis arising from such events should not be discounted. While this report was being prepared, coalition forces in Yemen – one of the world's most food-insecure countries – intensified their attacks on agricultural infrastructure. In June 2017, overland routes that carry 40 per cent of Qatar's food imports – including just under a fifth of its wheat imports – were closed as part of a blockade. Such developments should be the catalyst

[7] Authors' own analysis. For full details and sources, see Annex 2.

for policymakers to prepare for worst-case scenarios, especially given the growing risks from extreme weather events.[8]

Moreover, these risks are increasing, driven by three distinct trends. First, dependency on chokepoints is growing (see Figure 2). For example, in the past decade and a half the share of internationally traded grain and fertilizers passing through at least one of the maritime chokepoints has increased from 43 to 54 per cent. A smaller but nonetheless significant share – 10 per cent – now depends on transit through one or more of the maritime chokepoints as the *only* viable shipping route, up from 6 per cent in 2000.

Figure 2: Annual maritime chokepoint throughput of maize, wheat, rice and soybean, 2000 and 2015



Sources: Chatham House Maritime Analysis Tool; Chatham House (2017), resourcetrade.earth, http://resourcetrade.earth (2015 data).

Growing international trade means that chokepoint dependency is likely to increase for the foreseeable future. Some chokepoints will come under more pressure than others. Rapid and continued growth in exports from the Black Sea region will increase dependence on the Turkish Straits, particularly for wheat. At the same time, sustained demand growth in China (averaging around 14 per cent a year for soybean imports over the past 15 years) will continue to increase shipments from crop exporters in the West via the Panama Canal and the Strait of Malacca.

Second, climate change is increasing the threat of disruption by acting as a hazard multiplier across all three categories of chokepoint risk. It will increase the frequency and severity of extreme weather, leading to more regular closures of chokepoints and greater wear and tear on infrastructure. Rising sea levels will threaten the integrity of port operations and coastal storage infrastructure, and will increase their vulnerability

[8] Press reports indicate that up to 40 per cent of Qatar's total food imports are transported via Saudia Arabia. Wintour, P. (2017), 'Gulf plunged into diplomatic crisis as countries cut ties with Qatar', *Guardian*, 5 June 2017, https://www.theguardian.com/world/2017/jun/05/saudi-arabia-and-bahrain-break-diplomatic-ties-with-qatar-over-terrorism. Meanwhile, Chatham House estimates that 17 per cent of Qatar's wheat imports are sourced from countries involved in the blockade at the time of writing – Saudi Arabia, Bahrain, the UAE and Egypt. Chatham House Maritime Analysis Tool; Chatham House (2017), resourcetrade.earth.

to storm surges. Climate change is expected to aggravate drivers of conflict and instability. It will also lead to more frequent harvest failures, increasing the risk of governments imposing ad hoc export controls.

Chokepoint failures threaten to compound market fragility by contributing to higher costs and longer delays in delivery, and by making major supply disruptions more likely

Climate change may also increase the risk of concurrent supply disruptions. As extreme weather events become more common, the chances of coincidental disruptions occurring at different locations are likely to increase. Examples might include distant chokepoints being simultaneously disrupted by different weather systems, or a major chokepoint in one part of the world being closed during a harvest failure in a crop-growing region elsewhere. In such circumstances, market impacts are compounded. For example, if a hurricane comparable in ferocity to Hurricane Katrina in 2005 were to shut down US exports from the Gulf of Mexico at the same time as extreme rainfall rendered Brazil's roads impassable (the latter happened in 2013), up to 50 per cent of global soybean exports could be affected. If this in turn occurred in conjunction with a Black Sea heatwave similar to the one recorded in 2010, around 51 per cent of global soybean shipments, together with 41 per cent and 18 per cent of global maize and wheat exports respectively, could be halted or delayed.[9]

Third, chronic underinvestment in infrastructure is creating a double deficit – of capacity with respect to growing trade volumes, and of resilience with respect to climate change. The US's inland waterways are old, congested, vulnerable to drought and flood, and likely to start failing in the near future; its Gulf Coast ports are vulnerable to hurricanes and storm surges. Brazil's roads are poor and often rendered impassable by rain and subsidence. The Black Sea region requires significant investment in transport infrastructure, but regional instability is a deterrent to this. Each of the above-mentioned regions must mobilize significant investment in the coming decades to prevent bottlenecks and climate vulnerability worsening, but all face challenges in doing so.

The outlook for increasing chokepoint risk must also be understood in the context of mounting pressures on agricultural markets. Growth in cereal yields has fallen behind projected growth in cereal demand. Climate change is expected to exert a further drag on crop yields and become an increasingly destabilizing influence on global harvests. As a consequence, international markets are likely to become tighter and more volatile while dependence upon them increases. Chokepoint failures threaten to compound market fragility by contributing to higher costs and longer delays in delivery, and by making major supply disruptions more likely.

Which countries are most at risk?

Countries vary significantly in their exposure to chokepoint disruption. The criticality of a given chokepoint to a particular country depends not only on the share of imports that pass through it, but on how easily supply can be rerouted or secured through alternative means in the event of the chokepoint's closure. For example, although almost 87 per cent of China's grain and fertilizer imports are shipped through at least one maritime chokepoint, only 4 per cent pass through chokepoints for which no alternative route exists.

[9] Authors' analysis based on annual share of global exports, Chatham House Maritime Analysis Tool.

Conversely, just over a third of grain imports for the Middle East and North Africa (MENA) – the most food import-dependent region in the world – pass through at least one maritime chokepoint for which there is no alternative route. MENA countries rely on grain exports from the Black Sea, transported via Russian and Ukrainian railways and ports and on through the Turkish Straits; should these straits close for any reason, no alternative maritime routing option exists. This high degree of chokepoint exposure is compounded by proximity to the three Arabian maritime chokepoints (the Suez Canal, the Strait of Hormuz and the Strait of Bab al-Mandab), which determine market access for many countries in the region. Historical links between food insecurity and political/social instability make the region's extreme exposure to chokepoint risk a particular cause for concern.

Structural vulnerabilities in poor countries amplify the potential consequences of chokepoint disruptions

Structural vulnerabilities in poor countries amplify the potential consequences of chokepoint disruptions. In these countries, household spending on food and levels of pre-existing undernutrition are high, and the capacity of governments to respond is low. At the same time, the poor quality and limited extent of transport infrastructure – such as deep-water ports, railways and silos – in many developing countries also create local chokepoints and contribute to higher food prices.

Among low-income food-deficit countries (LIFDCs), a cluster of African countries have high exposure to maritime chokepoints with no alternative routes.[10] Many LIFDCs are also dependent on US exports and thus heavily exposed to US inland and coastal chokepoints. For example, Honduras sources 77 per cent of its maize imports and 88 per cent of its wheat imports from the US, and in Ethiopia the shares are 36 per cent and 27 per cent.[11]

The risk of chokepoint disruption is by no means a concern for low-income countries alone. Japan and South Korea rank among the most exposed countries in the world, despite also being two of the richest. Though not considered food-insecure by traditional metrics, both countries rely heavily on food imports that transit one, two or three chokepoints. Just under three-quarters of Japan's maize and wheat imports pass through the Panama Canal; and one-third of South Korea's wheat and maize imports pass through the Suez Canal, Strait of Bab al-Mandab and Strait of Malacca.

Chokepoint risks are poorly understood and poorly managed

Despite their importance to the availability and price of food, chokepoints are systematically overlooked in assessments of strategic food security. This stands in marked contrast with analyses of energy security, where chokepoint risk has been a key consideration for years and international governance mechanisms have emerged to manage it.

The most obvious exception to this picture is China, which is acutely aware of its exposures. It actively invests in overseas infrastructure to relieve pressure on existing chokepoints (e.g. as a major investor in Brazilian infrastructure); to diversify supply routes (e.g. through construction of a railway across South America

[10] Burundi, Djibouti, Eritrea, Ethiopia, Kenya, Liberia, Mozambique, Rwanda, Sudan, Tanzania and Uganda.
[11] Other examples: Afghanistan, Tanzania, Burkina Faso and Sierra Leone rely on the US for 61 per cent, 37 per cent, 27 per cent and 33 per cent respectively of their maize needs. Based on data for latest available year – 2015 for all but Afghanistan and Sierra Leone, for which 2014 data are used. Chatham House (2017), resourcetrade.earth, http://resourcetrade.earth.

to lessen reliance on the Panama Canal); and to increase its operational footprint along its supply chains (Chinese companies are ubiquitous owners and operators of ports and trans-shipment hubs).

However, the lack of cooperative approaches for dealing with food chokepoint risk is troubling, as it raises the prospect of uncoordinated, unilateral responses as states scramble to secure supply in the event of a major disruption, deepening the crisis as they do so.

Recommendations

Reducing chokepoint risk in the food system is a long-term project. New institutional and governance arrangements need to be negotiated and implemented at international and national level, existing infrastructure strengthened and new infrastructure built. Work must begin now for the necessary measures to be in place before climate change becomes a major source of disruption and instability. This report proposes five areas for action.

1. Integrate chokepoint analysis into mainstream risk management and security planning.

If supply chain risks are to be managed effectively, analysis of chokepoint dependence and chokepoint risk needs to be incorporated into risk management and security planning across a range of sectors – food security, national security, disaster risk management – at international, national and subnational level.

The United Nations should identify critical food security corridors

The United Nations (UN) should identify critical food security corridors around which memoranda of understanding may be developed for the protection of critical food trade through maritime chokepoints in the event of a disruption.

Governments in food-importing countries should undertake assessments of exposure and vulnerability to chokepoint risk at the national and subnational level. This process should be led by government agencies, in collaboration with international organizations such as the World Bank and UN Food and Agriculture Organization (FAO), bringing in donor agencies where appropriate.

Donor governments should commit funding to develop infrastructure disaster resilience strategies with national governments, agencies and a range of stakeholders to ensure effective coordination in disaster response and to mitigate negative food security outcomes.

Governments in at-risk countries should share knowledge, to the extent that it exists, on chokepoint risk assessment and management. One historical example was the US's sharing of lessons learned, in terms of disaster response and recovery strategies, with other climate-vulnerable nations following Hurricane Katrina in 2005. These lessons were then used to inform the development of those countries' own national contingency plans.

Providers of food security indicators should incorporate chokepoints in their analyses. For example, food security assessments produced by the FAO, the World Bank, the Famine Early Warning Systems Network (FEWS NET), the Economist Intelligence Unit and Maplecroft should take account of chokepoint risk.

2. Invest in infrastructure to ensure future food security.

This report argues that one of the biggest risks to agricultural trade is a lack of adequate infrastructure. Closing the infrastructure gap is not simply a question of more construction; new developments must be able to withstand increasingly hostile weather as they age.

The G20 should establish a taskforce on climate-compatible infrastructure. Building on the work of the Global Infrastructure Hub and the Task Force on Climate-related Financial Disclosures, the taskforce should establish common principles and guidelines for critical infrastructure that is resilient to future climate impacts.

The G20 should establish a taskforce on climate-compatible infrastructure

Governments should set up national-level independent infrastructure committees to advise on investment and policy decisions relating to major transport infrastructure. These committees should be cross-government in structure and should sit outside of parliamentary cycles to ensure a long-term, cross-sectoral perspective.

Multilateral development banks should prioritize investment projects that diversify food supply sources when taking decisions on funding – whether for regional trans-shipment hubs, transport infrastructure to boost market connectivity and support ‘multimodality’,[12] or strategic reserves and storage infrastructure.

Governments should adopt a ‘landlord’ model of public ownership and private concessions for critical infrastructure in countries in which state-owned railways, roads, waterways or ports are failing as a result of poor management or underinvestment.

Governments in major food-exporting regions facing infrastructure financing deficits should seek strategic ‘win-win’ investment partnerships with key trading partners willing to finance infrastructure to relieve pressure on inland and coastal chokepoints.

International financial institutions and donors should continue to invest in agricultural extension services, agricultural research and development, and the cultivation and scaling up of alternative crops to support a diversified grain production base (particularly for crops with a relatively high tolerance to climate stresses) and so reduce exposure – both at national and systemic level – to chokepoint disruption.

3. Enhance confidence and predictability in global trade.

New governance measures are needed to counter the contagious spread of export controls – such as those seen during the 2007–08 food crisis. Where possible, policies and investment should promote the diversification of the global grain production base, and reduce dependence on a small number of exporting regions and their inland and coastal chokepoints.

[12] Multimodality refers to transport infrastructure designed to support and facilitate the movement of cargo from one mode of transport to another.

The World Trade Organization (WTO) should instigate a process to continually reduce the scope for export restrictions. An outright ban on such restrictions would be ideal; a less ambitious approach could include clarifying and strengthening WTO rules to make it harder for governments to introduce ad hoc policies.

Developed food-exporting countries should reform trade-distorting farm support. Such support promotes systemic reliance on a handful of mega-crops and a small number of grain-exporting regions. Instead, public funds should be directed to supporting alternative sources of grain production around the world, in order to diversify global production and reduce import dependence elsewhere. A priority should be to direct such funding to farming in sub-Saharan Africa, where yield gaps remain while cereal demand is growing rapidly; this could be complemented with funding to support production of alternative crops.

4. Develop emergency supply-sharing arrangements and smarter strategic storage.

Strategic reserves, and provisions for their release and distribution at times of supply shortage or when prices are rising, are critical to managing chokepoint risk. However, unlike oil markets, no international institution exists to manage the risk of a major supply interruption in agricultural markets.

The FAO, UN World Food Programme (WFP) or Agricultural Market Information System (AMIS) should establish an emergency response mechanism among major players in the global food trade*,* modelled in part on that of the International Energy Agency in oil markets, to agree rules on coordination during acute market disruptions, including on the release and sharing of stocks and on measures to relax 'biofuel mandates'.[13]

Governments in food-deficit regions should agree storage and emergency sharing arrangements at regional level

Grain-trading partners should pursue collaborative arrangements to store grain in destination markets – that is, beyond the location at which chokepoints could interrupt supply. This would involve exporting countries entering into extra-territorial storage agreements with importing countries – whereby the exporter stores grain in the importing country – to provide assurance over availability in the event of supply dislocations. Agreements would need to specify emergency access rights and pricing arrangements.

At-risk countries – such as those in the Horn of Africa and the MENA region – should ensure sufficient domestic stocks are available to meet needs during plausible worst-case supply disruptions. Where government capacity to manage stocks is lacking, arrangements to outsource stockholding at target levels to the private sector could be explored.

Governments in food-deficit regions should agree storage and emergency sharing arrangements at regional level to reduce collective vulnerability to chokepoint disruption. Facilities should be positioned strategically to bypass potential blockages and to spread the risk of damage or obstruction.

[13] National policies that mandate certain levels of biodiesel or bioethanol blends in transportation fuel.

5. Build the evidence base around chokepoint risk.

Strengthening the evidence base around the importance of chokepoints to food security, and enhancing understanding of the nature and severity of disruptive hazards, are key first steps in the translation of chokepoint analysis into policy. These steps will require both new avenues of research and new modes of thinking about critical infrastructure.

Researchers should connect existing models of transport network dynamics with real-time food trade data to enable the modelling of rerouting options in cases of major disruption to maritime or coastal chokepoints. Expanded data functionality could provide the basis for the development of disaster management strategies. Where data are not open-source, research councils should support partnerships between the private sector and the research community that advance understanding of chokepoint risk while protecting commercially sensitive data.

AMIS should work with governments to harmonize nationally reported, macro-level transport infrastructure and asset data

AMIS should broaden its scope to include systemic chokepoints. An expanded remit should include risk assessment relating to the capacity and performance of systemic chokepoints, and evaluation of potential disruptions to them. In addition to raising awareness of chokepoint-related food security risks, such an initiative would promote the monitoring, disclosure and harmonization of data at national level, ultimately supporting better risk management.

Multinational institutions should integrate ongoing monitoring of chokepoint congestion and failures within existing frameworks for tracking infrastructure investments and infrastructure performance, to inform the identification of investment priorities. Examples of frameworks that could be adapted for this purpose include the OECD's International Transport Forum (ITF) and the World Economic Forum's *Global Competiveness Report*.

AMIS should work with governments to harmonize nationally reported, macro-level transport infrastructure and asset data, and to track spending and performance in the sector as a means to inform and attract multilateral and private-sector financiers.

Climate scientists and infrastructure industry associations should bridge the gap between climate impact modelling and infrastructure resilience planning, through industry-led dialogues that centre on the needs and constraints of infrastructure operators, and that support the downscaling of climate projections to sub-regional or project level.

Research councils and other funders should establish multidisciplinary frameworks to encourage the research community to address key knowledge gaps in the fields of food security, transport networks, disaster resilience, infrastructure development, infrastructure governance, risk assessment and climate science. Research is most urgently needed on at-risk food-importing regions and climate-exposed food-supply hubs.

1. Introduction

Key points

- Global supply of grain and fertilizer is highly concentrated among a handful of producer regions, and international trade is increasingly important to global food security.
- Population growth, dietary change, slowing yield growth and increasing resource stresses are tightening the supply–demand balance in many countries, heightening their reliance on imported food.
- International trade relies on a network of overland and maritime transport routes along which lie 14 chokepoints of global strategic importance.
- These chokepoints are exposed to a range of disruptive hazards that threaten to delay critical food shipments, yet the risk of such supply disruption remains largely overlooked in current food security analyses.
- New approaches to risk management in global food trade are needed to build understanding of chokepoint risk and to develop robust risk mitigation strategies.

Global food security rests upon international trade in a handful of crops. Maize, wheat, rice and soybean together provide around two-thirds of the world's harvested crop calories.[14] While production of these crops is concentrated in a few 'breadbasket' regions, demand is ubiquitous and reliance on imports is rising.

Population growth, shifting dietary preferences and growing demand for biofuels are driving up demand for grain[15] – for food, animal feed and fuel.[16] Global crop production will need to double by 2050 to keep pace with this demand.[17] But a combination of biophysical and socioeconomic factors – including heat stress, water scarcity, declining soil fertility, soil erosion, intensive cultivation practices and poor nutrient management – is slowing global growth in crop yields.[18] These supply challenges are heightened by the fact that opportunities for the expansion of cropland are limited: agriculture already uses 12 per cent of the world's ice-free

[14] Tilman, D., Balzer, C., Hill, J. and Befort, B. L. (2011), 'Global food demand and the sustainable intensification of agriculture', *Proceedings of the National Academy of Sciences [PNAS]*, 108(5): 20260–20264, doi: 10.1073/pnas.1116437108 (accessed 30 Apr. 2017); Cassman, K. G. (1999), 'Ecological intensification of cereal production systems: Yield potential, soil quality, and precision agriculture', *PNAS,* 96(11): 5952–5959, doi: 10.1073/pnas.96.11.5952 (accessed 2 May 2017).
[15] 'Grain' in this report refers to maize, wheat, rice and soybean, both for direct human consumption and for use as animal feed. For an analysis of the share of global crop production used for human consumption, animal feed, biofuel feedstock and other purposes, see Cassidy, E. S., West, P. C., Gerber, J. S. and Foley, J. A. (2013), 'Redefining agricultural yields: from tonnes to people nourished per hectare', *Environmental Research Letters,* 8(3): 034015, doi: 10.1088/1748-9326/8/3/034015 (accessed 2 May 2017).
[16] Foley, J. A., Ramankutty, N., Brauman, K. A., Cassidy, E. S., Gerber, J. S., Johnston, M., Mueller, N. D., O'Connell, C., Ray, D. K., West, P. C., Balzer, C., Bennett, E. M., Carpenter, S. R., Hill, J., Mondreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S., Tilman, D. and Zaks, D. P. M. (2011), 'Solutions for a cultivated planet', *Nature*, 478: 337–342 (accessed 2 May 2017).
[17] Tilman et al. (2011), 'Global food demand and the sustainable intensification of agriculture'; Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Pretty, J., Robinson, S., Thomas, S. M. and Toulmin, C. (2010), 'Food Security: The Challenge of Feeding 9 Billion People', *Science*, 327: 812–818, doi: 10.1126/science.1185383 (accessed 2 May 2017).
[18] Ray, D. K., Ramankutty, N., Mueller, N. D., West, P. C. and Foley, J. A. (2012), 'Recent patterns of crop yield growth and stagnation', *Nature Communications*, 3: 1293, doi: 10.1038/ncomms2296 (accessed 2 May 2017); D'Odorico, P., Carr, J. A., Laio, F., Ridolfi, L. and Vandoni, S. (2014), 'Feeding humanity through global food trade', *Earth's Future,* 2(9): pp. 458–469, doi: 10.1002/2014EF000250 (accessed 28 Feb. 2017).

land; should this share surpass 15 per cent, we risk triggering abrupt, potentially catastrophic environmental change.[19] Marked asymmetries exist between the food demand and supply profiles of high-income countries and those of low-income countries. Populations are expected to grow fastest in low-income countries – in North Africa, the Middle East, and parts of East and Southern Africa – that already struggle to meet food demand through domestic production alone.[20] Yield improvement rates for wheat, maize and rice are too slow to meet projected demand in these markets, or indeed in others where grain provides a high share of total calorie consumption.[21] At a global level, 36 per cent of crop calories grown are diverted in the form of livestock feed to the production of meat and dairy products,[22] which are consumed principally in high- and middle-income countries.[23] An additional 4 per cent of crop calories are used in the production of biofuels, an industry dominated by high- and middle-income countries.[24]

On top of these trends, the exacerbating effects of climate change on crop yields and on yield variability[25] are likely to be particularly great in regions where a food production deficit exists and where widespread poverty means that vulnerability to price volatility is high.[26]

1.1 The importance of trade to food security

Despite these asymmetries, global food availability is increasing; the share of the world's population with insufficient food supply fell from 52 per cent in 1965 to 3 per cent in 2005.[27] But these gains have been won largely through increased trade rather than through an increase in self-sufficiency;[28] nearly 1 billion people

[19] Foley et al. (2011), 'Solutions for a cultivated planet'; Rockström, J., Steffen, W., Noone, K., Persson, A., Chapin, F. S., Lambin, E., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H., Nykvist, B., De Wit, C. A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P. K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R. W., Fabry, V. J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P. and Foley, F. (2009), 'Planetary boundaries: exploring the safe operating space for humanity', *Ecology and Society,* 14(2): 32, http://www.ecologyandsociety.org/vol14/iss2/art32 (accessed 30 Apr. 2017).
[20] Larson, D. F., Lampietti, J., Gouel, C., Cafiero, C. and Roberts, J. (2013), 'Food Security and Storage in the Middle East and North Africa', *The World Bank Economic Review,* 28(1): 48–73, doi: 10.1093/wber/lht015 (accessed 30 Apr. 2017); Fader, M., Rulli, M. C., Carr, J., Dell'Angelo, J., D'Odorico, P., Gephart, J. A., Kummu, M., Magliocca, N., Porkka, M., Prell, C., Puma, M. J., Ratajczak, Z., Seekell, D. A., Suweis, S. and Tavoni, A. (2016), 'Past and present biophysical redundancy of countries as a buffer to changes in food supply', *Environmental Research Letters*, 11: 055008, doi: 10.1088/1748-9326/11/5/055008 (accessed 30 Apr. 2017); Fader, M., Gerten, D., Krause, M., Lucht, W. and Cramer, W. (2013), 'Spatial decoupling of agricultural production and consumption: quantifying dependences of countries on food imports due to domestic land and water constraints', *Environmental Research Letters*, 8: 014046: doi. 10.1088/1748-9326/8/1/014046 (accessed 30 Apr. 2017).
[21] Ray, D. K., Mueller, N. D., West, P. C. and Foley, J. A. (2013), 'Yield Trends Are Insufficient to Double Global Crop Production by 2050', *PLoS ONE*, 8(6): e66428, doi: 10.1371/journal.pone.0066428 (accessed 2 May 2017).
[22] Cassidy et al. (2013), 'Redefining agricultural yields'.
[23] Bailey, R., Froggatt, A. and Wellesley, L. (2014), *Livestock – Climate Change's Forgotten Sector: Global Public Opinion on Meat and Dairy Consumption*, Research Paper, London: Royal Institute of International Affairs, https://www.chathamhouse.org/sites/files/chathamhouse/field/field_document/20141203LivestockClimateChangeForgottenSectorBaileyFroggattWellesleyFinal.pdf (accessed 2 May 2017).
[24] Cassidy et al. (2013), 'Redefining agricultural yields'; Popp, J., Harangi-Rákos, M., Gabnai, Z., Balogh, P., Antal, G. and Bai, A. (2016), 'Biofuels and Their Co-Products as Livestock Feed: Global Economic and Environmental Implications', *Molecules*, 21(285), doi: 10.3390/molecules21030285 (accessed 2 May 2017).
[25] Lobell, D. B., Schlenker, W. and Costa-Roberts, J. (2011), 'Climate trends and global crop production since 1980', *Science*, 333(6042): 616–620, doi: 10.1126/science.1204531 (accessed 2 May 2017); Ray, D. K., Gerber, J. S., MacDonald, G. K. and West, P. C. (2015), 'Climate variation explains a third of global crop yield variability', *Nature Communications*, 6: 5989, doi: 10.1038/ncomms6989 (accessed 2 May 2017).
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[27] Porkka, M., Kummu, M., Siebert, S. and Varis, O. (2013), 'From Food Insufficiency towards Trade Dependency: A Historical Analysis of Global Food Availability', *PLoS One,* 8(12), doi: 10.1371/journal.pone.0082714 (accessed 23 May 2017).
[28] Ibid.

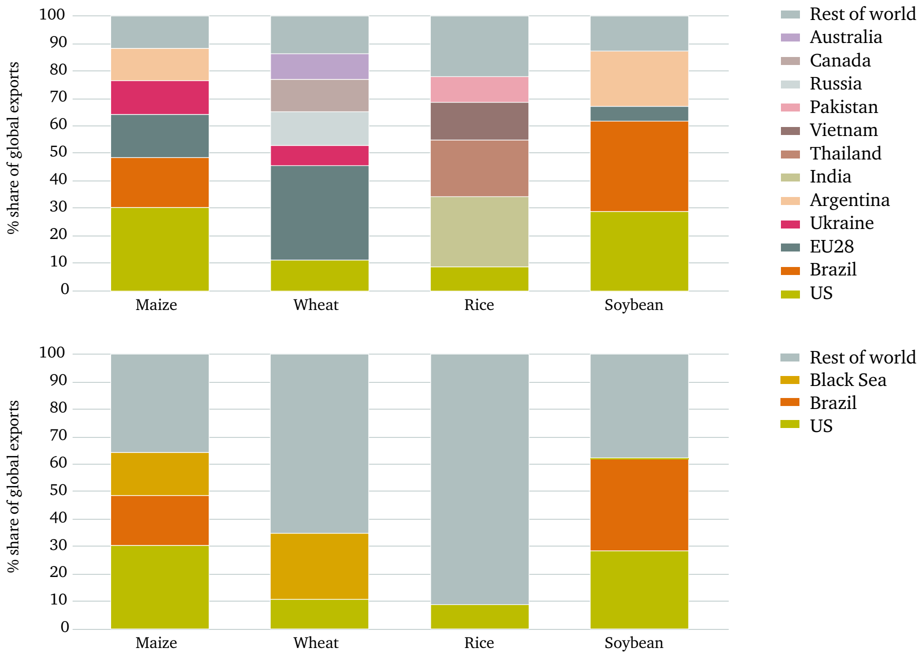
worldwide now rely on international trade to meet their food needs.[29] Significant disparities in food security remain at regional level.

Today, the food system is a complex network of trade dependencies and international supply chains, characterized by increasing interconnectivity.[30] Between 2000 and 2015, the volumes of agricultural commodities traded on international markets increased by 127 per cent to 2.2 billion tonnes.[31] International trade in fertilizers, while accounting for only a small share of bulk commodity trade,[32] is also critical to global food security. The vast majority of countries import fertilizer, and the primary producers of fertilizer around the world are themselves major importers. Long-run trends suggest that the rise in the importance of trade to global food security is set to continue.

1.2 The global food network

One of the key features of this complex system is the concentration of grain supply in a handful of crop-supplying regions (see Figure 3),[33] and the even greater concentration of fertilizer supply (see Box 1). Local communities are connected to, and reliant on, production sites often thousands of miles away.

Figure 3: Concentration of global exports of maize, wheat, rice and soybean by country and region of origin, 2015



Source: Chatham House (2017), resourcetrade.earth. 2015 data, showing all countries which account for 5 per cent or more of global exports in the given commodity.

[29] Fader et al. (2013), 'Spatial decoupling of agricultural production and consumption'.
[30] Puma, M. J., Bose, S., Chon, S. Y. and Cook, B. I. (2015), 'Assessing the evolving fragility of the global food system', *Environmental Research Letters,* 10(2): 024007, doi: 10.1088/1748-9326/10/2/024007 (accessed 27 Feb. 2017).
[31] Data from 2000 and 2015 for all agricultural products – Chatham House (2017), resourcetrade.earth (accessed 28 Apr. 2017).
[32] Fertilizers made up only 1.7 per cent of the weight and 1.5 per cent of the value of global commodities trade in 2015. See Chatham House (2017), resourcetrade.earth; Open Sea (2016), 'Fertilizers: A minor bulk cargo with major importance', https://opensea.pro/blog/shipping-fertilizers (accessed 21 Mar. 2017).
[33] Puma et al. (2015), 'Assessing the evolving fragility of the global food system'.

Today, just under a quarter of all food for direct human consumption is traded on international markets.[34] The total share of production traded internationally in 2014 was 24 per cent for wheat, 11 per cent for maize and 60 per cent for soybean.[35] Rice remains a relatively thinly traded commodity – just 5 per cent of production is exported, since the majority is consumed in the country where it is produced and trade is often restricted by national export and import tariffs[36] – but traded volumes as a share of global production have been rising since the late 1980s.[37] In the case of fertilizers, around 36 per cent of total production in 2014 was traded.[38]

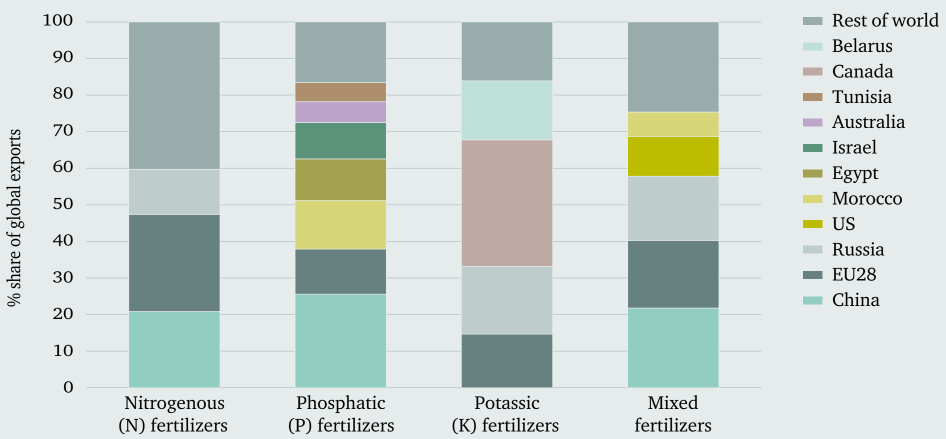
International trade in food and agricultural inputs relies on a global web of transport systems

International trade in food and agricultural inputs in turn relies on a global web of transport systems. A complex network of railways, waterways, ports, sea lanes and storage infrastructure supports the movement of crops and fertilizers from farm or factory to port, region to region, and port to hinterland. This network is particularly dense in and around three major food production and export sites:[39] the US, Brazil and the Black Sea.[40]

Box 1: Concentration of fertilizer supply

Just six countries – Belarus, Canada, China, India, Russia and the US – account for 70 per cent of global fertilizer production,[41] and over 50 per cent of global exports (see Figure 4). The concentration of supply is even higher for certain types of fertilizer: for example, Belarus, Canada and Russia produce over 90 per cent of the world's supply of potassium chloride (also known as muriate of potash or MOP).[42]

Figure 4: Concentration of global fertilizer exports, by producer



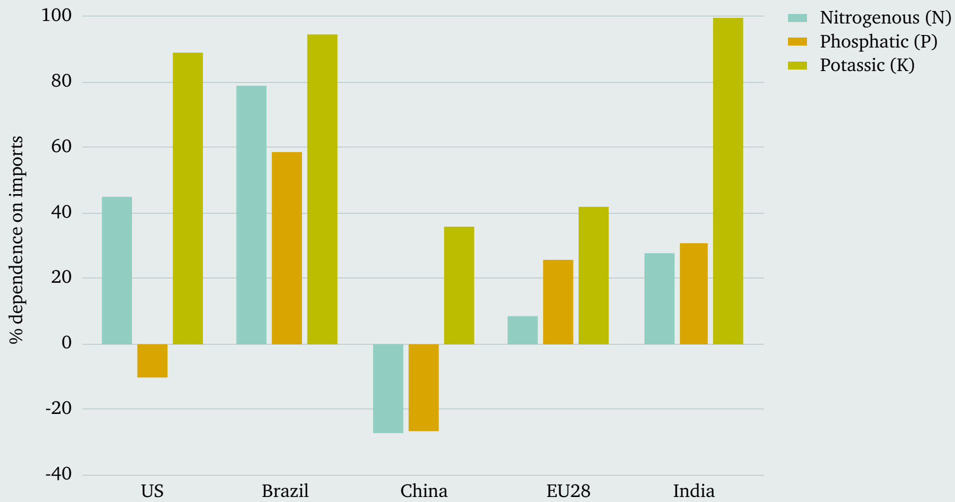
Source: Chatham House (2017), resourcetrade.earth. 2015 data, showing all countries which account for 5 per cent or more of global exports in the given commodity.

[34] D'Odorico et al. (2014), 'Feeding humanity through global food trade'.
[35] Production data for 2014 – FAO (2017), 'Crops', FAOSTAT, http://www.fao.org/faostat/en/#data/QC.
[36] Muthayya, S., Sugimoto, J. D., Montgomery, S. and Maberly, G. F. (2014), 'An overview of global rice production, supply, trade, and consumption', *Annals of the New York Academy of Sciences,* 1324: 7–14, doi: 10.1111/nyas.12540 (accessed 23 May 2017).
[37] Mohanty, S. (2016), 'Trends in global rice trade', http://irri.org/rice-today/trends-in-global-rice-trade (accessed 12 Apr. 2017).
[38] Production and trade data for 2014 in tonnes of nutrients – FAO (2016), 'Fertilizers', FAOSTAT, http://fenix.fao.org/faostat/beta/en/#data/RF (accessed 21 Jun. 2017).
[39] See freight transport network maps in OECD/ITF (2017), *ITF Transport Outlook 2017*, Paris: OECD Publishing, doi: 10.1787/9789282108000-en (accessed 10 Apr. 2017).
[40] The Black Sea region is defined in this report as consisting of Bulgaria, Kazakhstan, Moldova, Romania, Russia and Ukraine. Together, Russia and Ukraine account for 73 per cent of the Black Sea's wheat exports (resourcetrade.earth); for this reason, the two countries are the main focus of Black Sea analysis throughout the report.
[41] Data for 2014 in tonnes – FAO (2016), 'Fertilizers', FAOSTAT.
[42] Ibid.

The major centres of demand for traded fertilizer include some of the world's largest grain producers (see Figure 5). The US relies on imports for around 89 per cent of its domestic potash usage and over 40 per cent of its nitrogen usage.[43] Brazil has ramped up its fertilizer imports to sustain rapid growth in crop production;[44] imports supply over 50 per cent of the country's fertilizer demand in all three nutrient types.[45] Ukraine is a net exporter of nitrogenous fertilizers but depends on imports for over 80 per cent of its phosphatic and potassic fertilizer needs.[46]

China is an exporter of nitrogenous and phosphatic fertilizers and a significant producer of potassic fertilizer;[47] the majority of the latter is put to domestic use (with additional supply of potassic fertilizer imported from Belarus, Canada and Russia). India is a major importer of phosphate and potash. The EU depends on imports for around 40 per cent of its potash needs, but is a large producer and exporter of nitrogenous and mixed fertilizers.[48]

Figure 5: Import dependency of major food producers by nutrient type, 2014



Source: FAO (2016), 'Fertilizers', FAOSTAT, data for 2014 in tonnes of nutrients, http://fenix.fao.org/faostat/beta/en/#data/RF (accessed 12 Apr. 2017).
Note: Import dependency = (imports – exports) / (domestic production + imports – exports), expressed as a percentage. Black Sea not included owing to missing data for Russian fertilizer trade.

1.3 Food trade chokepoints

Supply chains are only as reliable as their weakest links, and the most critical parts of the international food transport network are the junctures – which this report terms 'chokepoints' – along shipping and overland trade routes through which transit especially high volumes of commodities. Chokepoints can be natural features or man-made infrastructure, and include maritime straits, seaports, road and rail networks,

[43] Data for 2014 in tonnes of nutrients – FAO (2016), 'Fertilizers', FAOSTAT.
[44] Rahm, M. R. (2015), 'Outlook for Brazil', presentation at the Sixth CRU-GPCA Fertilizer Convention, Dubai, UAE, http://gpcafertilizers.com/2015/wp-content/uploads/2015/10/Mike-Rahm-The-Mosaic-Company.pdf (accessed 28 Apr. 2017).
[45] Data for 2014 in tonnes – FAO (2016), 'FAOSTAT: Fertilizers'.
[46] Ibid.
[47] Ibid.
[48] Trade data for 2015 – Chatham House (2017), resourcetrade.earth.

and inland waterways. This report explores 14 food trade chokepoints of systemic importance: eight maritime, three coastal and three inland (see Figure 6).[49]

Figure 6: Global food trade chokepoints

At these locations, international trade is particularly vulnerable to dislocation. A major interruption at one or more of these chokepoints could result in supply shortages and price rises; smaller backlogs can add to delays, spoilage and transport costs, constraining market responsiveness and increasing prices and volatility. Many small-scale interruptions, and a number of large-scale disruptions, have already caused delays and/or damage to shipments (as discussed in Chapter 3). Such incidents may not grab headlines in isolation, but they cumulatively impair market functioning and hint at what is plausible in a worst-case scenario.

1.3.1 An underexplored risk to food security

Reliance on a small number of export and transit hubs presents a fundamental risk to the global food system

Reliance on a small number of export and transit hubs presents a fundamental risk to the global food system. Although market interconnection has enhanced food security in food-deficit countries by reducing their exposure to localized agricultural shortfalls, it has also increased their exposure to systemic shocks in distant regions.[50] In effect, by doing more trade, import-dependent countries have swapped idiosyncratic local risks for systemic global risk.

Chokepoint functioning also has commercial implications, potentially affecting profit margins along entire supply chains. Increasing chokepoint risk matters to the wide array of corporate and financial actors involved in the production, processing, transport and financing of resources. This presents both risks and opportunities.

[49] The methods for identifying these chokepoints and assessing their importance to global food security are described in Chapter 2 and Annex 1.
[50] Puma et al. (2015), 'Assessing the evolving fragility of the global food system'; Goldin, I. and Mariathasan, M. (2014), *The Butterfly Defect: How Globalization Creates Systemic Risks and What to Do about It,* Princeton and Oxford: Princeton University Press.

For example:

- For farmers, chokepoint disruptions could restrict access to markets.
- Major disruptions of chokepoints could cause shipments to be delayed or cancelled, with financial implications for commodity traders with obligations to fulfil.
- For shipping and logistics companies, chokepoint disruptions could cause delays and raise costs. On the other hand, disruptions could also boost revenues if customers are forced to use longer alternative routes.
- For insurers and reinsurers, chokepoint disruptions and their consequences are a potential source of underwriting losses. However, they are also a potential source of additional underwriting business.
- For humanitarian agencies, chokepoint disruptions may prevent emergency food aid and other vital supplies from being distributed to communities in need.
- For consumers globally, supply interruptions could prompt government policies and market responses that lead to price spikes in many commodities, directly or indirectly affecting food prices.

Box 2: Chokepoints, trade and security

A 'chokepoint' is a vulnerable point of congestion along a route. In land warfare, this might consist of a narrow pass or valley that renders an army vulnerable to attack; the naval equivalents are the maritime straits that have long been a concern for national security and military strategy.

Today, chokepoints on major trade routes remain of strategic importance due to the high volumes of energy products, food, metals and minerals that pass through them. This is particularly true during periods of upheaval or conflict: a nation that controls a chokepoint controls the supply of goods that pass through it. Russia's annexation of Crimea in 2014, thus bringing the Kerch Strait within Russian territorial waters, offers a case in point. Seizure of the peninsula has afforded Russia control over traffic into and out of the Sea of Azov, enabling it to impose levies on Ukrainian grain exports from the ports of Berdyansk and Mariupol should it so wish, while increasing its reach over the region's marine oil and gas reserves.[51]

During times of peace, nations with influence or control over naturally occurring or man-made chokepoints can harness them for strategic leverage or economic benefit; Panama and Egypt both profit from levies on traffic transiting the Panama and Suez canals. Mutually beneficial trade deals may be brokered between neighbouring countries on the basis of access to chokepoints and the international markets to which they link, as India, Iran and Afghanistan plan to do under the Chabahar Agreement.[52]

[51] Agrimoney.com (2014), 'Ukraine crisis may cause grain export 'bottleneck'', 24 March 2014, http://www.agrimoney.com/news/news.php?id=6907 (accessed 31 Jan. 2017); Bugajski, J. and Doran, P. B. (2016), *Black Sea Rising: Russia's Strategy in Southeast Europe*, Washington, DC: Center for European Policy Analysis.
[52] Panda, A. (2016), 'India, Iran, Afghanistan Finalize Chabahar Port Agreement', *The Diplomat*, 18 April 2016, http://thediplomat.com/2016/04/india-iran-afghanistan-finalize-chabahar-port-agreement (accessed 2 Sep. 2016).

Perhaps most importantly of all, chokepoints matter to governments (see Box 2). Food is a strategic resource, and a government unable to ensure sufficient, affordable food for its population is a government at risk, as recent bouts of instability in international markets illustrate. For example, the 2007–08 global food price crisis was accompanied by protests in 61 countries and riots in 23.[53] In late 2010 and early 2011, prices climbed higher still, following a poor wheat harvest in the Black Sea region and subsequent export bans. This contributed to protests in North Africa – one of the world's major wheat-importing regions – that became the Arab Spring.

Despite the importance of chokepoints to market functioning, and the importance of market functioning to political stability, chokepoints are rarely, if at all, considered in assessments of strategic food security. This stands in marked contrast to energy markets, which are also crucial to global stability but where analysts pay particular attention to the security of chokepoints. Obvious examples in the energy sector include pipelines, refineries and critical sea lanes such as the straits of Hormuz and Malacca, through which 30 per cent[54] and 27 per cent[55] respectively of all seaborne-traded oil passes each year. A temporary closure of the Strait of Hormuz that resulted in oil exports falling by 10 million barrels a day for three months, for example, could create a supply shortfall in Asian markets equivalent to 26 per cent of consumption, with profound implications for the region and international prices more generally.[56]

Chokepoints are rarely, if at all, considered in assessments of strategic food security

There is a need for similar scenario-based risk assessment in global food markets, as the temporary closure of a critical trade chokepoint could have a destabilizing effect on food security and on global security more widely. This implies three tasks. Firstly, the chokepoints of systemic importance to global food trade need to be identified. Secondly, an exploration of the potential for disruption to these chokepoints is required, together with an assessment of the likely impact of such disruption at global and national level. Thirdly, on the basis of this assessment, robust risk management strategies need to be formulated, both to reduce the likelihood of a disruption and to prepare for its eventuality.

1.4 Aims and structure of this report

In order to undertake this assessment, Chatham House has developed two new analytical tools: the Chatham House Maritime Analysis Tool (CH-MAT, see Chapter 2) and the Chatham House Food Security Dashboard (CH-FSD, see Chapter 4). Together, these tools allow for a first-of-its-kind analysis of grain and fertilizer volumes transiting critical chokepoints in the global food system. They also allow for a hazard assessment to pinpoint locations of systemic vulnerability.

In this report, we build a picture of the systemic importance of chokepoints to global trade in grain and fertilizer. We augment this with a qualitative assessment of the

[53] von Braun, J. (2008), *Food and Financial Crises: Implications for Agriculture and the Poor*, Washington, DC: International Food Policy Research Institute, https://core.ac.uk/download/pdf/6289061.pdf (accessed 5 Sep. 2016).
[54] US Energy Information Administration (2014), 'World Oil Transit Chokepoints', https://www.eia.gov/beta/international/regions-topics.cfm?RegionTopicID=WOTC (accessed 9 Sep. 2016).
[55] Metelitsa, A. and Kupfer, J. (undated), *Oil and Gas Resources and Transit Issues in the South China Sea*, Briefing, Asia Society Policy Institute, http://asiasociety.org/files/SouthChinaSea_OilGas_brief.pdf (accessed 9 Sep. 2016).
[56] Mitchell, J. (2014), *Asia's Oil Supply: Risks and Pragmatic Remedies*, Research Paper, London: Royal Institute of International Affairs, https://www.chathamhouse.org/publication/asia%E2%80%99s-oil-supply-risks-and-pragmatic-remedies (accessed 28 Apr. 2017).

threats of disruption, in order to assess chokepoint risk at national level and the implications for food security.

The degree of chokepoint risk in the global food system is likely to increase

We find that chokepoint risk matters to food security in various ways, ranging from worst-case scenarios in which a global harvest shock coincides with major interruptions at one or more critical chokepoints, to the insidious 'background' consequences of weather, congestion, disrepair and weak governance. Importantly, we argue that the degree of chokepoint risk in the global food system is likely to increase due to the growing dependency of food security on international trade, and to the increasingly disruptive influence of climate change.

Accordingly, we recommend strategies to strengthen risk assessment, risk mitigation and risk preparedness. We assess opportunities for governments – and for a range of private actors involved in agricultural production, trade and transport logistics – to manage the threat of chokepoint disruption to food security.

1.4.1 Report structure

Chapter 2 introduces 14 food trade chokepoints of global strategic importance – eight maritime, three coastal and three inland. It also considers trends and potential changes affecting food trade, as well as developments in transport and technology – such as the possible opening up of new trade routes – that could be of future relevance to chokepoint risk.

Chapter 3 explores the range of hazards to which food trade chokepoints are exposed. It assesses the relative risk profiles of the 14 chokepoints and considers the way in which hazards interact to create compound and cascading risks through global food markets.

Chapter 4 outlines Chatham House's approach to assessing chokepoint risk and food insecurity at national level. It considers chokepoint risk for individual countries, exploring how exposure and vulnerability differ across national settings, and identifies the countries most exposed to chokepoint risk.

Chapter 5 assesses the efficacy of existing policy responses and commercial responses to food supply risk, and the extent to which the risk of chokepoint disruption is currently addressed at national and international level. It identifies major gaps in investment and governance.

Chapter 6 draws conclusions on the importance of food trade chokepoints, the relevance of robust risk management policies and international cooperation, and the implications of inaction for food security in the near and long term. It then offers a series of recommendations for management of chokepoint risk at national and international level.

2. Chokepoints in Global Food Trade

Key points

- Global dependence on maritime chokepoints has increased since 2000, particularly in respect of internationally traded wheat and maize supplied by Black Sea producers to China and other growing markets in Asia.
- Poor infrastructure quality and lack of investment are constraining operations in six critical coastal and inland chokepoints. Located in Brazil, the US and the Black Sea region, these chokepoints connect major crop-producing regions to global markets.
- Trends in the transport sector – including the opening up of alternative shipping routes and the containerization of dry bulk goods – may ease the pressure on certain trade chokepoints in the future, but the overall picture will remain one of increasing systemic reliance on 14 critical junctures.

Increasing reliance on trade to meet food demand brings increasing dependence on the infrastructural backbone of transnational trade networks. While a growing body of literature explores systemic and compound risks in interconnected food markets and evaluates the potential for localized shocks to cascade through international supply chains,[57] physical trade channels and chokepoints are rarely considered in any detail or depth. Below, we introduce 14 chokepoints that are of global strategic importance to food trade and estimate the share and volume of trade in maize, wheat, rice, soybean and fertilizers that passes through these chokepoints each year.

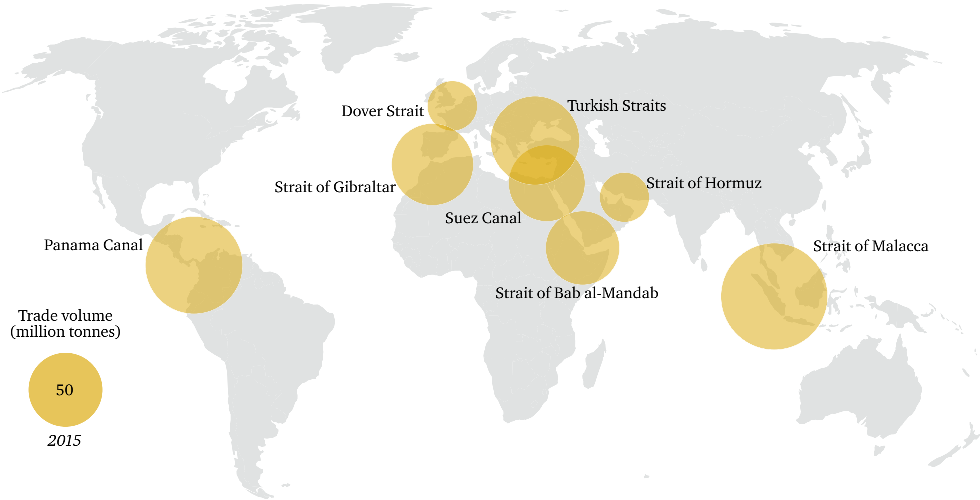
2.1 Maritime chokepoints

2.1.1 The eight maritime chokepoints

By virtue both of their geographical location and geo-economic value, eight maritime chokepoints stand out as systemically important to international trade in commodities (food and other agricultural products, as well as energy, minerals and metals). The specific relevance of these chokepoints to global food markets reflects the fact that they lie along transnational routes linking major grain and fertilizer exporters, transit centres and importers in food-deficit regions (see Figure 7). The likely costs and/or delays associated with rerouting trade, should one of these chokepoints be closed, are such that their functioning may be deemed critical to maintaining secure supply and price stability in global food markets.

[57] Benton, T. G., Fairweather, D., Graves, A., Harris, J., Jones, A., Lenton, T., Norman, R., O'Riordan, T., Pope, E. and Tiffin, R. (2017), *Environmental tipping points and food system dynamics: Main Report*, Global Food Security Programme, UK, http://www.foodsecurity.ac.uk/assets/pdfs/environmental-tipping-points-report.pdf (accessed 22 May 2017); Bailey, R., Benton, T. G., Challinor, A., Elliott, J., Gustafson, D., Hiller, B., Jones, A., Jahn, M., Kent, C., Lewis, K., Meacham, T., Rivington, M., Robson, D., Tiffin, R. and Wuebbles, D. J. (2015), *Extreme weather and resilience of the global food system*, final project report from the UK-US Taskforce on Extreme Weather and Global Food System Resilience, http://www.foodsecurity.ac.uk/assets/pdfs/extreme-weather-resilience-of-global-food-system.pdf (accessed 24 Mar. 2017); Moser, S. C. and Finzi Hart, J. A. (2015), 'The long arm of climate change: societal teleconnections and the future of climate change impacts studies', *Climatic Change*, 129: 13–26, doi: 10.1007/s10584-015-1328-z (accessed 22 May 2017).

Figure 7: Annual maritime chokepoint throughput of maize, wheat, rice and soybean by volume, 2015

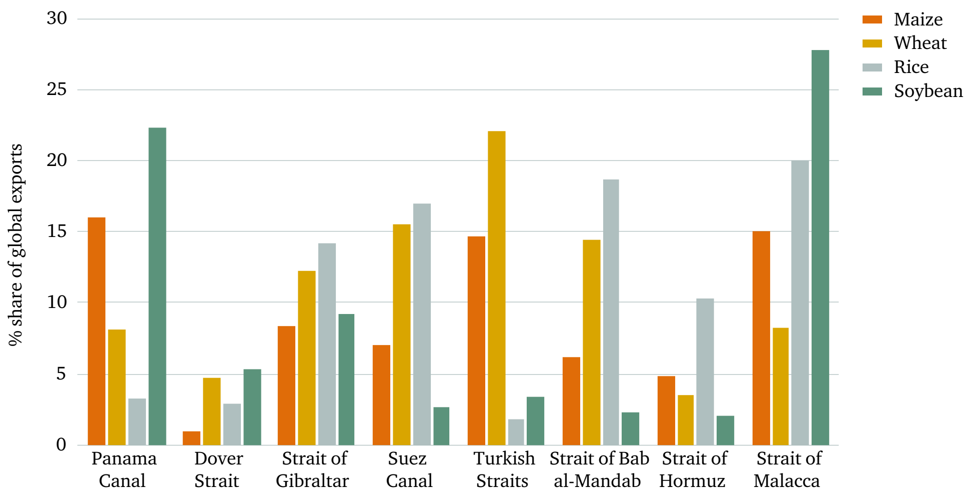


Sources: Chatham House Maritime Analysis Tool; Chatham House (2017), resourcetrade.earth (2015 data).

Fifty-five per cent of internationally traded maize, wheat, rice and soybean is shipped through at least one maritime chokepoint

A large share of global trade in strategic crops passes through one or several of these chokepoints. Fifty-five per cent of internationally traded maize, wheat, rice and soybean is shipped through at least one maritime chokepoint.[58] A smaller but nonetheless significant share of this trade – 11 per cent – relies on transit through one or both of the maritime chokepoints for which no alternative route exists: the Turkish Straits and the Strait of Hormuz. In terms of weight, annual throughput of grain ranges from 24 million tonnes (via the Strait of Hormuz) to 108 million tonnes (via the Strait of Malacca).

Figure 8: Annual maritime chokepoint throughput of maize, wheat, rice and soybean as a share of total trade, 2015



Sources: Chatham House Maritime Analysis Tool; Chatham House (2017), resourcetrade.earth (2015 data).

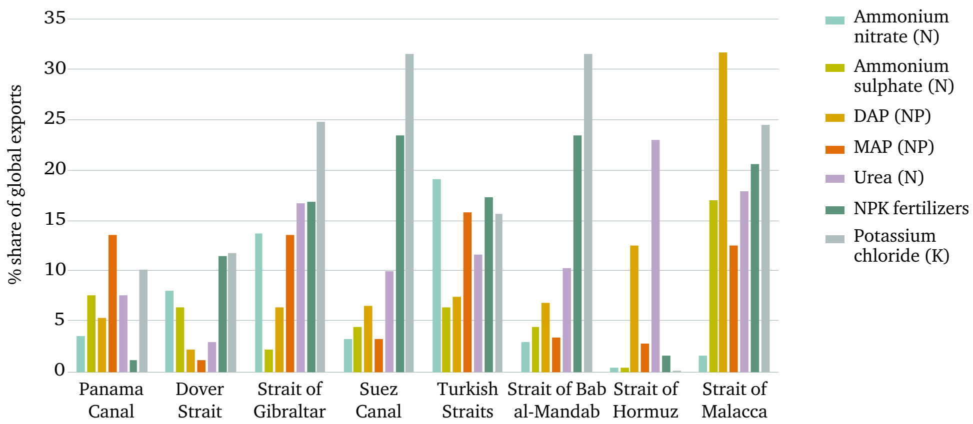
[58] All chokepoint throughput figures used in this report are drawn from the Chatham House Maritime Analysis Tool and Chatham House (2017), resourcetrade.earth. See Box 3 and Annex 1.

At an aggregate level, the Panama Canal and the Strait of Malacca, two of the key gateways linking Western and Asian markets, see the most significant annual throughput of the four strategic crops.

Looking at the data commodity by commodity, the Panama Canal, Turkish Straits and Strait of Malacca emerge as the most critical chokepoints in terms of throughput as a share of global trade in specific crops. Around a fifth of global soybean exports and a sixth of global maize exports transit the Panama Canal each year; much of this trade originates in the US and Brazil and is destined for Asian markets. At the same time, a fifth of global wheat exports and a sixth of global maize exports pass through the Turkish Straits, reflecting the importance of the Black Sea producers for global export markets. And over a quarter of global soybean exports – of which a large proportion is destined for the rapidly expanding pig and poultry markets in China, East Asia and Southeast Asia[59] – transit the Strait of Malacca, along with 20 per cent of internationally traded rice (see Figure 8).

These same maritime junctures are also critical for global fertilizer trade (see Figure 9). A high proportion of potassium chloride – the most heavily traded fertilizer – transits maritime chokepoints: 25 per cent passes through the Strait of Gibraltar; 32 per cent through the Suez Canal and the Strait of Bab al-Mandab; and 25 per cent through the Strait of Malacca. These flows are dominated by China-bound shipments from Belarus, Russia and Canada, China being the second-largest importer of potassium chloride after the US. Maritime chokepoints are also important for phosphate trade: 32 per cent of trade in diammonium phosphate (DAP), one of the most widely used phosphate fertilizers,[60] transits the Strait of Malacca each year.

Figure 9: Share of global trade in fertilizers passing through key maritime chokepoints, 2015



Sources: Chatham House Maritime Analysis Tool; Chatham House (2017), resourcetrade.earth (2015 data).
Note: Refers only to fertilizer products accounting for more than 3 per cent of total fertilizer trade in 2015. MAP stands for monoammonium phosphate, DAP for diammonium phosphate.

[59] Brack, D., Glover, A. and Wellesley, L. (2016), *Agricultural Commodity Supply Chains: Trade, Consumption and Deforestation*, Research Paper, London: Royal Institute of International Affairs, https://www.chathamhouse.org/sites/files/chathamhouse/publications/research/2016-01-28-agricultural-commodities-brack-glover-wellesley.pdf (accessed 3 Mar. 2017); Lee, T., Tran, A., Hansen, J. and Ash, M. (2016), 'Major Factors Affecting Global Soybean and Products Trade Projections', US Department of Agriculture (USDA) Economic Research Service, 2 May 2016, https://www.ers.usda.gov/amber-waves/2016/may/major-factors-affecting-global-soybean-and-products-trade-projections (accessed 16 Apr. 2017).
[60] Farchy, J. and Terazono, E. (2015), 'India's economy drives demand for phosphate fertilizer', *Financial Times,* 29 May 2015, https://www.ft.com/content/417bf3a8-0538-11e5-8612-00144feabdc0 (accessed 9 Mar. 2017).

Box 3: Estimating flows through maritime chokepoints

In this report, a maritime chokepoint is defined as a narrow corridor, connecting two bodies of water along international sea lines of communication (SLOCs), that is liable to congestion or blockage and for which no expedient alternative maritime route exists. The eight major maritime chokepoints we selected were identified through analyses of international transport networks,[61] heat-maps of global shipping based on vessels' Automatic Identification System (AIS) data,[62] and expert judgment from the maritime industry. An overview of their location and width is provided below (Table 1).

Table 1: Overview of maritime chokepoints

Chokepoint	Littoral state(s)	Linked bodies of water	Width at narrowest point (km)
Panama Canal	Panama	Pacific Ocean–Atlantic Ocean	0.3
Dover Strait	UK, France	Atlantic Ocean–North Sea	33
Strait of Gibraltar	Spain, Morocco	Atlantic Ocean–Mediterranean Sea	13
Turkish Straits	Turkey	Mediterranean Sea–Black Sea	1
Suez Canal	Egypt	Mediterranean Sea–Red Sea	0.2
Strait of Bab al-Mandab	Djibouti, Eritrea, Yemen	Red Sea–Arabian Sea	32
Strait of Hormuz	Oman, UAE, Iran	Arabian Sea–Persian Gulf	48
Strait of Malacca	Indonesia, Malaysia, Singapore	Indian Ocean–South China Sea	2.5

Estimates of agricultural and fertilizer trade passing through these chokepoints are presented throughout this report. These are based on the Chatham House Maritime Analysis Tool (CH-MAT), which couples a global database of bilateral trade flows with a set of assumptions on the physical maritime trade routes used to transport bulk agricultural products between geographical regions, in order to estimate annual throughput at each of the chokepoints.

This is the first set of estimates of its kind in the literature on food trade and food security. The CH-MAT allows us to estimate the weight or value of flows passing through these chokepoints, both at the global aggregate level and in terms of bilateral flows between countries or regions. A more detailed methodology can be found in Annex 1.

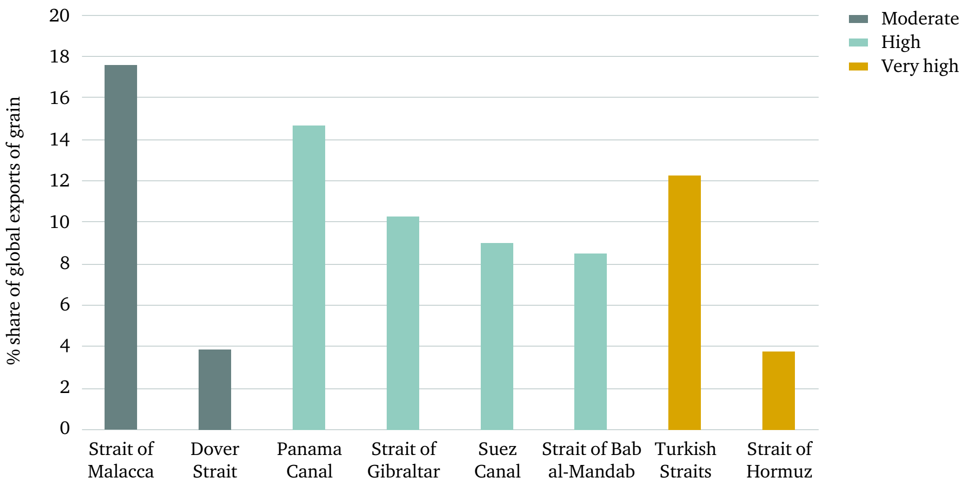
The importance of each maritime chokepoint depends not only on the volume of trade that passes through it each year, but on its strategic importance to connectivity, whether at a global, regional or national level. We can divide the eight maritime chokepoints into three separate categories of 'criticality' according to the availability of alternative routes (see Figure 10):

- **Moderate.** An alternative route is available that offers only a minimal delay for shipments (though potentially less favourable shipping conditions) and does not incur significant additional costs. This applies to the Strait of Malacca and the Dover Strait.

[61] See, for example, Rodrigue, J.-P., Comtois, C. and Slack, B. (2017), *The Geography of Transport Systems*, New York: Routledge, https://people.hofstra.edu/geotrans/.
[62] AIS is an automatic system for vessel tracking. See, for example, www.shipmap.org.

- **High.** The only alternative route is one that would incur a significantly longer transit time and significantly higher shipping costs. This applies to the Panama and Suez canals, the Strait of Gibraltar and the Strait of Bab al-Mandab.
- **Very high.** No obvious alternative maritime route is available. This applies to the Strait of Hormuz and the Turkish Straits.

Figure 10: Maritime chokepoint criticality



Sources: Chatham House Maritime Analysis Tool; Chatham House (2017), resourcetrade.earth (2015 data).

Looking beyond the global level, it is also important to consider the importance of specific chokepoints for individual regions or countries (whether exporters or importers). For example:

- Algeria, Tunisia, Libya and Egypt lie on the Mediterranean Sea, sandwiched between the Strait of Gibraltar to the west and the Suez Canal and Strait of Bab al-Mandab to the east. Seventy per cent of wheat imports into these four countries pass through at least one chokepoint for which there is no convenient alternative.
- Seventy-seven per cent of wheat exports from Russia, Ukraine and Kazakhstan must pass through the Turkish Straits. And 39 per cent of those exports have to continue through both the Suez Canal and the Strait of Bab al-Mandab to reach the Indian Ocean and their destinations beyond.
- The Panama Canal links the US's main maize and soybean export hub on the Gulf of Mexico coast to Asian markets. The canal handles 36 per cent and 49 per cent respectively of the US's exports of these two commodities.
- India, the second-largest consumer of phosphate fertilizers after China,[63] and the largest importer of diammonium phosphate (DAP), is dependent on China for 58 per cent of its DAP imports. One hundred per cent of this trade has to pass through the Strait of Malacca.

[63] Phosphate fertilizer consumption in tonnes of nutrients for 2014 – FAO (2016), 'Fertilizers', FAOSTAT (accessed 9 Mar. 2017).

Other maritime chokepoints are of little systemic importance but matter to particular importing countries or regions. The Danish Straits, for example, are a series of three shallow channels connecting the Baltic Sea to the North Sea. They are of significance to the global oil trade[64] and also a major thoroughfare for the Baltic states. Tough navigating conditions mean collisions are relatively common in these straits.[65]

The Kerch Strait is another chokepoint of regional significance. Bordered by the Crimean Peninsula to the west and the Taman Peninsula to the east, it connects the Black Sea to the Sea of Azov. The strait is a major export channel for Black Sea grain, oil, minerals and timber, and is now under the control of Russia. Ukraine's announcement of a lawsuit against Russia concerning the latter's alleged violation of the UN Convention on the Law of the Sea (UNCLOS) signals the value of the Kerch Strait to Ukraine's future as a global commodity exporter.[66]

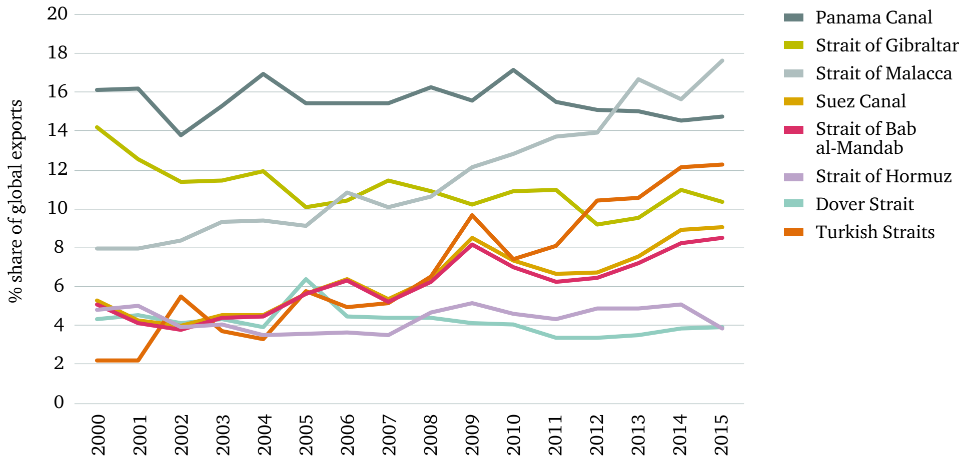
2.1.2 Increasing systemic importance of maritime chokepoints

Dependence on maritime chokepoints has climbed since the turn of the century

2.1.2.1 Rising dependence at the global level

Dependence on maritime chokepoints has climbed since the turn of the century. In 2000, a total of 42 per cent of global grain exports was shipped through one or several of the maritime chokepoints; in 2015, that total had risen to 55 per cent. The majority of this growth in traffic has been in wheat and maize, supplied by Black Sea producers to China and other booming markets in Asia. In the case of the Strait of Malacca, the most rapid rise in throughput (as a share of exports) has been in soybean, again reflecting rapid import growth in Asian countries, principally China.

Figure 11: Annual grain throughput of maritime chokepoints as share of global grain exports, 2000–15



Sources: Chatham House Maritime Analysis Tool; Chatham House (2017), resourcetrade.earth.

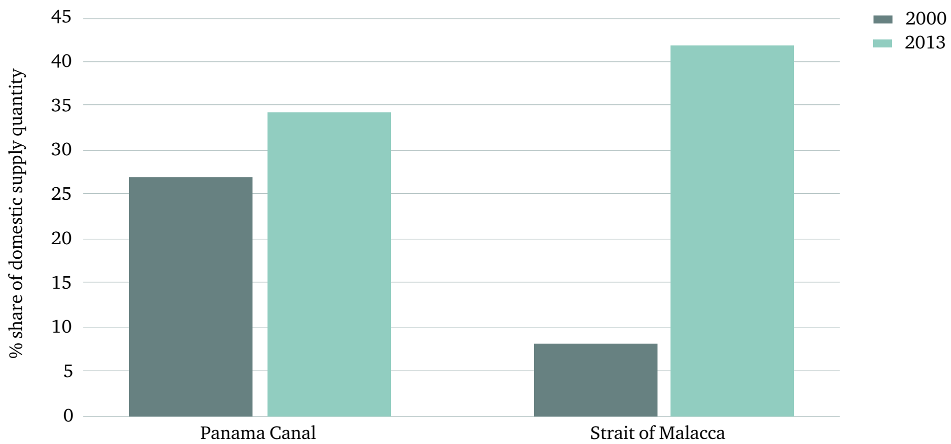
[64] Bender, J. (2015), 'These 8 narrow chokepoints are critical to the world's oil trade', *Business Insider UK*, 1 April 2015, http://uk.businessinsider.com/worlds-eight-oil-chokepoints-2015-4?r=US&IR=T (accessed 28 Apr. 2017).
[65] Baltic Marine Environment Protection Commission (2012), *Annual report on Shipping accidents in the Baltic Sea in 2012*, Helsinki: HELCOM, http://helcom.fi/Lists/Publications/Annual%20report%20on%20shipping%20accidents%20in%20the%20Baltic%20Sea%20area%20during%202012.pdf (accessed 28 Apr. 2017).
[66] Maritime Executive (2016), 'Ukraine Threatens UNCLOS Suit Over Crimean Waters', 23 August 2016, http://www.maritime-executive.com/article/ukraine-threatens-unclos-suit-over-crimean-waters (accessed 6 Mar. 2017).

The picture of rising throughput is not uniform, however. Certain maritime chokepoints (e.g. the Dover Strait, Strait of Hormuz) handle a similar share of global grain trade today compared to a decade ago, whereas at others there have been pronounced increases in traffic. For example, between 2000 and 2015, annual throughput as a share of global grain exports rose rapidly for the Turkish Straits, Suez Canal, Strait of Bab al-Mandab and the Strait of Malacca (see Figure 11). This was a consequence of growth in trade between the Black Sea, the Middle East and Asia.

2.1.2.2 China's increasing reliance on international markets

China's rapidly growing demand for imported soybean has important ramifications for trade through the Panama Canal and the Strait of Malacca – two of the gateways linking China with North American and South American soybean producers – and will continue to stimulate throughput increases in the coming years.[67] Between 2000 and 2013, the proportion of China's soybean imports shipped via the two chokepoints rose from the equivalent of 8 per cent of domestic consumption to 42 per cent for the Strait of Malacca, and from 27 per cent of domestic consumption to 34 per cent for the Panama Canal (see Figure 12).

Figure 12: China's soybean imports shipped through the Panama Canal and Strait of Malacca, as a proportion of supply for domestic use, 2000 and 2013



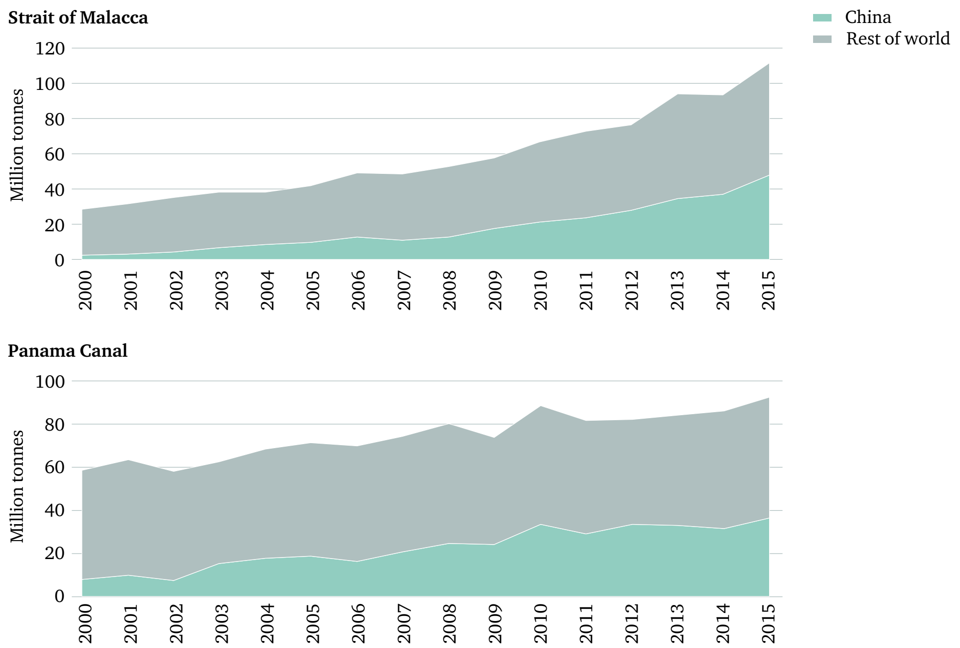
Sources: Domestic supply quantity data from FAO (2016), 'Food Balance Sheets', FAOSTAT, data only available up to 2013, http://www.fao.org/faostat/en/#data/FBS (accessed 23 May 2017). Import data from Chatham House (2017), resourcetrade.earth (2013 data).

Today, Chinese imports account for 43 per cent of trade in strategic agricultural commodities shipped through the Strait of Malacca and 39 per cent of those shipped through the Panama Canal (see Figure 13). This share – and China's strategic interest in the two chokepoints – looks set to be maintained in the future. Chinese demand is expected to account for nearly half of the growth in global food demand by 2050,[68] and the country's soybean imports are expected to exceed an annual total of 100 million

[67] Fukase, M. and Martin, W. J. (2016), 'Who Will Feed China in the 21st Century? Income Growth and Food Demand and Supply in China', *Journal of Agricultural Economics*, 67(1): 3–23, doi: 10.1111/1477-9552.12117 (accessed 22 Jul. 2016).
[68] Gillson, I. and Fouad, A. (2015), 'Introduction', in Gillson, I. and Fouad, A. (eds) (2015), *Trade Policy and Food Security: Improving Access to Food in Developing Countries in the Wake of High World Prices*, Directions in Development – Trade, Washington, DC: World Bank, https://openknowledge.worldbank.org/handle/10986/20537 (accessed 3 Mar. 2017).

tonnes by 2025.[69] While the expanded Panama Canal should be able to accommodate increased transit volumes, constraints on space and human resources in the Strait of Malacca may lead to more frequent delays – and potentially collisions – in this already crowded corridor.

Figure 13: Maize, wheat, rice and soybean imports through the Strait of Malacca and Panama Canal



Sources: Chatham House Maritime Analysis Tool; Chatham House (2017), resourcetrade.earth (2015 data).

2.1.2.3 Booming trade through the Arabian chokepoints

Annual throughput of food shipments via the Arabian chokepoints of the Suez Canal, Strait of Bab al-Mandab and Strait of Hormuz, en route to markets in the Middle East and North Africa (MENA), has grown rapidly in recent years.[70] Between 2000 and 2015, the region's wheat imports arriving through the Suez Canal grew by 120 per cent; those routed through the Strait of Bab al-Mandab rose by 98 per cent. Until 2014 the Strait of Hormuz exhibited a similar upward trend, with a 45 per cent increase in shipments on 2000 levels. (Shipments through the strait dropped by 47 per cent in 2015 as a result of significantly lower Saudi Arabian imports – the result of a boost to domestic wheat production and of a drawdown of large stocks.[71] However, volumes are expected to rise again following the completion in 2015 of the country's domestic wheat production programme.)[72] Between 2000 and 2013,

[69] Lee et al. (2016), 'Major Factors Affecting Global Soybean and Products Trade Projections'.
[70] Throughput levels dropped in 2010 following the Russian heatwave and subsequent wheat export ban. See Kramer, A. E. (2010), 'Russia, Crippled by Drought, Bans Grain Exports', *New York Times*, 5 August 2010, http://www.nytimes.com/2010/08/06/world/europe/06russia.html (accessed 21 Mar. 2017).
[71] USDA Foreign Agricultural Service (2016), 'Saudi Arabia Grain and Feed Annual', 14 March 2016, https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Grain%20and%20Feed%20Annual_Riyadh_Saudi%20Arabia_3-14-2016.pdf (accessed 23 Feb. 2017).
[72] Ibid.

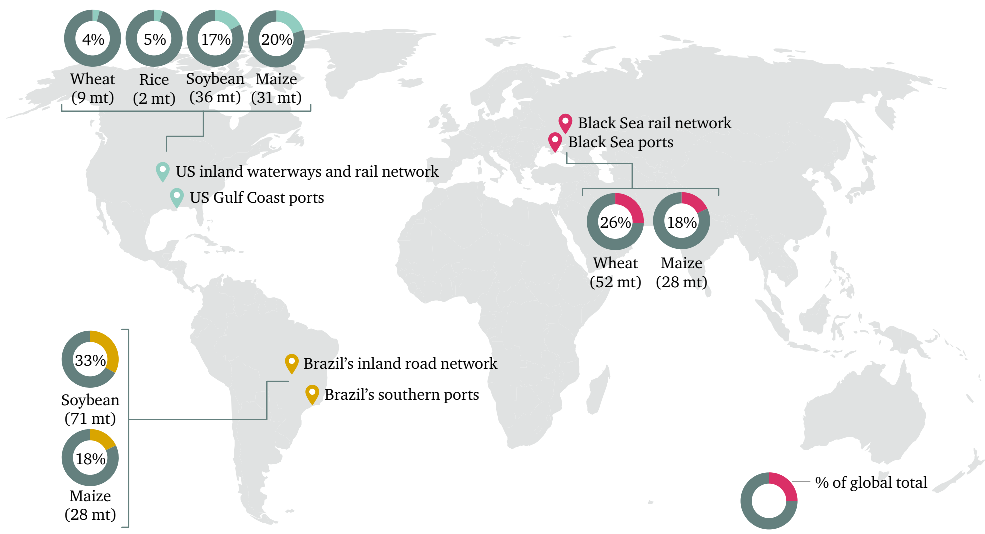
the MENA region's dependence on grain imports through these three chokepoints, measured as a share of domestic supply, rose by around 25 per cent.[73]

The World Bank predicts that strong population growth will drive a 63 per cent increase in cereal demand across Arab countries over the next 40 years,[74] but water scarcity and the limited supply of arable land will constrain domestic production. As a result, cereal imports into the MENA region – already the largest net importer of wheat in the world – are expected to rise by 95 per cent on 2010 levels by 2050.[75]

2.2 Coastal and inland chokepoints

In this section we consider the importance of export infrastructure connecting three major crop-producing regions with global markets. We focus on the links between coastal chokepoints (port areas of particular importance to food and fertilizer exports) and inland chokepoints (large-scale infrastructure corridors or networks linking producer regions with export hubs on the coast) in Brazil, the US and the Black Sea region (see Figure 14).[76]

Figure 14: Map of coastal and inland food system chokepoints, and percentage of key crops exported through those chokepoints in 2015



Note: mt = million tonnes.
Sources: Chatham House Maritime Analysis Tool; Chatham House (2017), resourcetrade.earth (2015 data).

[73] This is equivalent to an increase of 3 percentage points, from 13 per cent to 16 per cent of supply. Authors' own calculation based on imports through chokepoints as a share of domestic supply of wheat, maize, rice and soybean. Domestic supply quantity data from FAO (2016), 'Food Balance Sheets', FAOSTAT (data only available up to 2013); import data from Chatham House (2017), resourcetrade.earth.
[74] Battat, M. and Lampietti, J. (2015), 'The Grain Chain: Trade and Food Security in Arab Countries', in Gillson and Fouad (eds) (2015), *Trade Policy and Food Security* (accessed 8 Jul. 2016).
[75] Ibid.
[76] The US, Brazil, Russia and Ukraine together export 63 per cent of internationally traded maize, 64 per cent of internationally traded soybean and 32 of internationally traded wheat. While growers in Southeast Asia and China dominate global rice production, only 55 per cent of total exports are shipped beyond regional markets. Chatham House Maritime Analysis Tool; Chatham House (2017), resourcetrade.earth (2015 data).

Together, these regions accounted for 53 per cent of global exports of maize, wheat, rice and soybean in 2015. A major interruption at one or more of these inland and coastal chokepoints could clearly have serious consequences for international markets, particularly if it occurs during a harvest season when use of transport infrastructure peaks.

The capacity and efficiency of loading and unloading operations, storage facilities and external connections at ports are key determinants of food transport costs

The accumulation of apparently minor interruptions is also important. The capacity and efficiency of loading and unloading operations, storage facilities and external connections at ports are key determinants of food transport costs. The impact of inland delays on transport costs is estimated to be seven times greater than that of delays to ocean shipping.[77] Inefficiencies can cause deliveries to be delayed by weeks, leading to higher costs and spoilage of crops and fertilizers from heat and moisture.

2.2.1 Connecting farm to port in 'breadbasket' regions

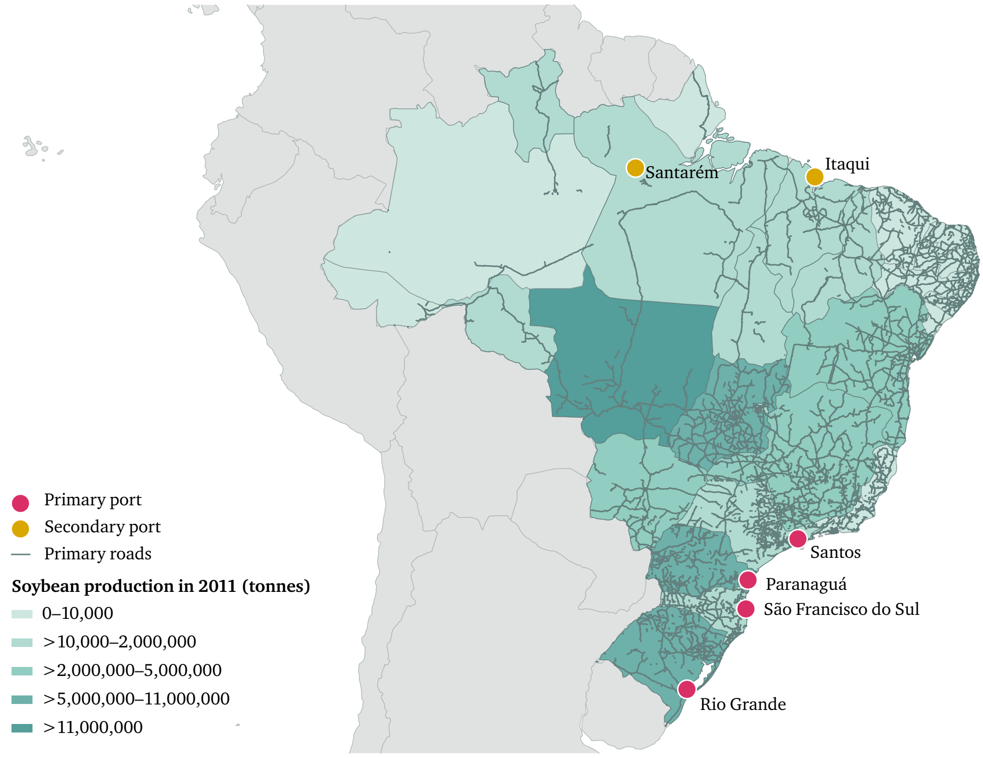
The following section looks in more depth at three coastal and three inland chokepoints, located in Brazil, the US and the Black Sea region. Each illustrates a range of challenges and constraints to secure and efficient chokepoint operation.

2.2.1.1 Brazil's inland road network and southern ports

Brazil is the world's largest exporter of soybean, and the majority of its exports are shipped from the ports on the southeast coast (see Figure 15): together, the ports of Santos, Paranaguá, Rio Grande and São Francisco do Sul handle just under a quarter of global soybean exports.[78] Linking these export hubs to the fertile producing regions inland is a crumbling network of roads, an estimated 70 per cent of which are in poor condition[79] and only 12 per cent of which are paved.[80] Alternative export routes are limited: the escarpment that forms Brazil's Atlantic coastline is a natural obstacle to port development,[81] while the sparsity and poor quality of the roads hinder the movement of soybean exports up to the northeastern port of Santarém.[82]

[77] Limão, N. and Venables, A. J. (1999), 'Infrastructure, Geographical Disadvantage, and Transport', Policy Research Working Paper No. 2257, http://siteresources.worldbank.org/EXTEXPCOMNET/Resources/2463593-1213976610278/01_Infrastructure_geographical_disadvantage_and_transport_costs.pdf (accessed 6 Jul. 2016).
[78] Authors' calculation based on Chatham House Resource Trade Database and Braun, K. (2016), 'No hang-ups for Brazilian soybean exports', Reuters, 19 May 2016, http://www.reuters.com/article/us-brazil-soybeans-braun-idUSKCN0Y910X (accessed 30 Jan. 2017).
[79] University of Southern Mississippi (2014), *Emerging South American Competitiveness to US Soybean Exports*, report compiled for the New Orleans World Trade Center.
[80] PwC (2013), 'Crunch Time For Brazilian Infrastructure', *Gridlines*, Spring 2013, https://www.pwc.com/gx/en/capital-projects-infrastructure/pdf/brazil-article.pdf (accessed 28 Apr. 2017).
[81] Marshall, T. (2015), *Prisoners of Geography. Ten Maps That Tell You Everything You Need to Know About Global Politics*, London: Elliott & Thompson.
[82] Global Commission on the Economy and Climate (2015), *Towards Efficient Land Use in Brazil*, http://2015.newclimateeconomy.report/wp-content/uploads/2015/09/Towards-Efficient-Land-Use-Brazil.pdf (accessed 8 Jul. 2016).

Figure 15: Brazil's inland road network and southern ports



Sources: Data for primary roads from MapCruzin (2017), 'Brazil Highways', http://www.mapcruzin.com/free-brazil-arcgis-maps-shapefiles.htm (accessed 19 Jun. 2017). Data for soybean production from USDA, FAS, International Production Assessment Division (2012), 'Brazil: Soybean Production by State', http://www.roachag.com/Portals/0/Research/Soybean_Production2012_State_Brazil_Geo.pdf (accessed 19 Jun. 2017).

The Brazilian government has embarked upon an ambitious US$100 billion programme of regulatory and infrastructure development in an effort to expand capacity, improve efficiency and lower transport costs.[83] It has taken steps to encourage private investment in its ports, loosening previously restrictive regulations on private concessionaires and introducing a range of tax and credit incentives, including infrastructure bonds, to encourage further private investment.[84] But this comes after decades of underinvestment. The density of road and rail networks remains less than half that of other key emerging economies,[85] and major ports in the south of Brazil are already at full capacity.[86]

The long distances from major producing regions to the coast, coupled with poorly maintained roads, result in very high transport costs compared with the US. The cost

[83] Poulden, G. (2013), 'Brazil creaks under the strain of meeting Chinese soya demand', 15 May 2013, *China Dialogue*, https://www.chinadialogue.net/blog/6013-Brazil-creaks-under-the-strain-of-meeting-Chinese-soya-demand/en (accessed 28 Apr. 2017); Salin, D. L. (2015), *Soybean Transportation Guide: Brazil 2014*, USDA Agricultural Marketing Service, July 2015, https://www.ams.usda.gov/sites/default/files/media/Brazil%20Soybean%20Transportation%20Guide%202014.pdf (accessed 28 Apr. 2017).
[84] OECD/FAO (2015), *OECD-FAO Agricultural Outlook 2015-2024,* Paris: OECD Publishing, www.fao.org/3/a-i4738e.pdf (accessed 24 Feb. 2017)*;* PwC (2013), 'Crunch Time For Brazilian Infrastructure'.
[85] OECD/FAO (2015), *OECD-FAO Agricultural Outlook 2015-2024.*
[86] Azoulai, D., Dunlop, H. and Kuettel, B. (2013), 'Big Bottleneck: A Weak Transportation Network Is Hurting Brazil's Once-hot Economy', Knowledge@Wharton, 20 December 2013, http://knowledge.wharton.upenn.edu/article/big-bottleneck-weak-transportation-network-hurting-brazils-hot-economy (accessed 28 Apr. 2017).

of trucking soybean from Mato Grosso, where nearly two-thirds of soybean for export to China are grown, to the seaport of Santos is estimated to account for around 20 per cent of the landed cost of soybean shipments to Shanghai.[87] The economic impact of these inefficiencies is significant: according to one estimate, logistics costs associated with undercapacity and transportation delays were equivalent to 12 per cent of Brazil's GDP in 2012.[88]

2.2.1.2 US inland waterways, rail network and Gulf Coast ports

Agricultural land in the US Midwest – among the most productive in the world – is linked to ports on the US's Gulf Coast, east coast and Pacific northwest coast by an expansive network of waterways, railways and roads. Around 60 per cent of US agricultural exports are transported from farm to port via the 12,000-mile inland marine transportation system (IMTS) – a network comprising the Mississippi River and its major tributaries; the Ohio River basin; the Great Lakes–St Lawrence Seaway; the Gulf Intra-Coastal Waterway; and the Snake River and Columbia River systems in the Pacific northwest (see Figure 16).[89]

Around 60% of US agricultural exports are transported from farm to port via the 12,000-mile inland marine transportation system

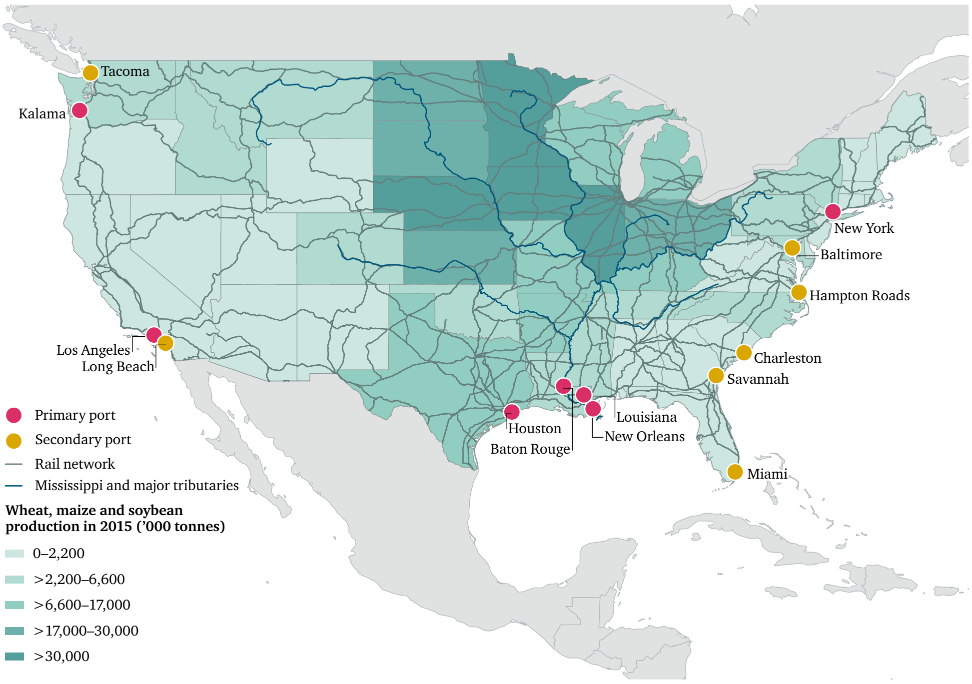
This inland waterway network is ageing and congested.[90] For example, the Upper Mississippi River and Illinois Waterway system is projected to reach 90 per cent of its annual throughput capacity by 2020, leading to delays and a significant proportion of traffic shifting to other transport modes.[91]

Significant shares of US wheat exports (around 63 per cent) and overall grain shipments (29 per cent) are transported by rail, and this network is equally strained:[92] 30 per cent of railway corridors are expected to be above capacity, and a further 25 per cent near or at full capacity, by 2035 unless significant improvements are made.[93]

Of the three port areas linked by these inland transport corridors, the most important for global food and fertilizer trade is the Gulf Coast. Over half of US grain exports are shipped from this region, accounting for 20 per cent of global maize exports, 17 per cent of global soybean exports and 4 per cent of global wheat exports. Shipments from Gulf Coast ports also account for 3 per cent of global fertilizer exports.

[87] Salin (2015), *Soybean Transportation Guide: Brazil 2014* (accessed 24 Feb. 2017).
[88] PwC (2013), 'Crunch Time For Brazilian Infrastructure'.
[89] Gordon, K., Lewis, M., Rogers, J. and Kinniburgh, F. (2015), *Heat in the Heartland: Climate Change and Economic Risk in the Midwest*, a Risky Business report, http://riskybusiness.org/site/assets/uploads/2015/09/RBP-Midwest-Report-WEB-1-26-15.pdf (accessed 6 Jul. 2016); Grier, D. (2009), *The Declining Reliability of the US Inland Waterway System*, Institute for Water Resources, US Army Corps of Engineers, http://onlinepubs.trb.org/onlinepubs/archive/Conferences/MTS/4A%20GrierPaper.pdf (accessed 6 Jul. 2016).
[90] Kruse, C. J. and Ahmedov, Z. (2011), *America's Locks & Dams: "A ticking time bomb for agriculture?",* Texas Transportation Institute and Center for Ports and Waterways, report prepared for United Soybean Board, https://unitedsoybean.org/wp-content/uploads/Americas_Locks_And_Dams.pdf (accessed 16 Apr. 2017); United States Department of Homeland Security/Office of Cyber and Infrastructure Analysis (2015), 'Aging and failing infrastructure systems: navigation locks', Critical Infrastructure Security and Resilience Note, prepared by Operational Analysis Division, 8 December 2015, https://info.publicintelligence.net/DHS-FailingLocks.pdf (accessed 6 Jul. 2016).
[91] US Army Corps of Engineers (USCE) (2012), *Inland Waterways and Export Opportunities*, http://www.lrd.USce.army.mil/Portals/73/docs/Navigation/PCXIN/Inland_Waterways_and_Export_Opportunities-FINAL_2013-01-03.pdf (accessed 6 Mar. 2017).
[92] USDA (2013), *A Reliable Waterway System is Important to Agriculture*, Agricultural Marketing Service, December 2013, https://www.ams.usda.gov/sites/default/files/media/Importance%20of%20Waterways%2012-2013.pdf (accessed 6 Jul. 2016); Envision Freight (2014), 'The Transportation of Grain', http://www.envisionfreight.com/value/pdf/Grain.pdf (accessed 6 Jul. 2016).
[93] Ibid.

Figure 16: US inland waterways, rail network and major ports



Sources: Data for rail network from Natural Earth (2015), 'Railroads', http://www.naturalearthdata.com/downloads/10m-cultural-vectors/railroads/ (accessed 19 Jun. 2017). Data for Mississippi and major tributaries from Natural Earth (2015), 'Rivers, Lake Centerlines', http://www.naturalearthdata.com/downloads/50m-physical-vectors/50m-rivers-lake-centerlines/ (accessed 19 Jun. 2017). Data for wheat, maize and soybean production from USDA, National Agricultural Statistics Service (2016), *Crop Production 2015 Summary*, https://www.usda.gov/nass/PUBS/TODAYRPT/cropan16.pdf (accessed 19 Jun. 2017).

Investment in infrastructure in the US is severely lacking; the country has one of the largest infrastructure investment deficits in the G20

Investment in infrastructure in the US is severely lacking; the country has one of the largest infrastructure investment deficits – the gap between the investment needed and investments already committed – in the G20.[94] The funding gap for inland waterways and ports through to 2025 is estimated at US$15.8 billion, and at US$43 billion through to 2040.[95] For surface transportation – roads, railways and bridges – the gap is even greater, at US$1.1 trillion through to 2025, and US$4.3 trillion through to 2040.[96] Budgetary constraints have caused long-term maintenance programmes and preventative action to be replaced by a reactive 'fix-it-as-it-fails' policy, with the result that repairs regularly interrupt traffic and the reliability of the country's ageing transport networks is further impaired.[97] A reported backlog of over 500 planned inland navigation projects to be undertaken by the US Army Corps of Engineers will alone cost an estimated US$38 billion to complete.[98]

[94] Mischke, J. (2015), 'Infrastructure finance: Myths and reality', presentation at Chatham House Infrastructure Finance Conference, London, 23 November 2015.
[95] US ASCE (2016), *Failure to Act: Closing the Infrastructure Investment Gap for America's Economic Future,* prepared by the Economic Development Research Group, Reston: American Society of Civil Engineers, http://www.infrastructurereportcard.org/wp-content/uploads/2016/05/2016-FTA-Report-Close-the-Gap.pdf (accessed 16 Aug. 2016).
[96] Ibid.
[97] Grier (2009), *The Declining Reliability of the US Inland Waterway System*.
[98] US Department of Transportation (2015), *Beyond Traffic 2045: Trends and Choices*, https://cms.dot.gov/sites/dot.gov/files/docs/Draft_Beyond_Traffic_Framework.pdf (accessed 18 Aug. 2016).

2.2.1.3 Black Sea ports and railways

Global wheat and maize supply increasingly depends on a handful of major export routes from the Black Sea region. However, chronic underinvestment in infrastructure raises questions about the viability of expansion plans.

Figure 17: Black Sea ports and railways

Sources: Data for maize- and wheat-producing areas: USDA Joint Agricultural Weather Facility (2017) – Ukraine (wheat): https://www.pecad.fas.usda.gov/rssiws/al/up_cropprod.htm?country=Ukraine&commodity=Wheat; Ukraine (maize): https://www.usda.gov/oce/weather/pubs/Other/MWCACP/Graphs/ukraine/ukraine_corn.pdf; Russia (wheat): https://www.usda.gov/oce/weather/pubs/Other/MWCACP/Graphs/russia/russia_wheat.pdf; Russia (maize): https://www.pecad.fas.usda.gov/rssiws/al/rs_cropprod.htm; Romania (wheat): https://www.usda.gov/oce/weather/pubs/Other/MWCACP/Graphs/eur/romw_wht.gif; Romania (maize): https://www.usda.gov/oce/weather/pubs/Other/MWCACP/Graphs/eur/romcrn.gif. (All data accessed 19 Jun. 2017.) Data for rail network: Natural Earth (2015), 'Railroads', http://www.naturalearthdata.com/downloads/10m-cultural-vectors/railroads/ (accessed 19 Jun. 2017).

Today, 60–65 per cent of Russian and Ukrainian grain exports are transported by rail to six ports on the Black Sea coast (see Figure 17).[99] Shipments from these ports also account for around 26 per cent of global wheat exports and 15 per cent of global fertilizer exports each year. Many railway lines, processing facilities, intermodal corridors and port facilities suffer from poor infrastructure quality. Grain storage facilities are at full capacity.[100] Poor handling facilities and ageing loading equipment contribute to high freight costs, delays and congestion. Partly as a result, farm-to-port

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[99] The six ports are Novorossiysk and Tuapse (Russia), Odessa and Ilyichevsk (Ukraine), Constanta (Romania) and Bourgas (Bulgaria). Centre for Transport Strategies (2014), *Ukraine – Agricultural Trade, Transport, and Logistic Advisory Services Activity*, Kiev: Centre for Transport Strategies, http://mtu.gov.ua/files/for_investors/Ukraine%20Agricultural%20Trade%20Transport%20and%20Logistic.pdf (accessed 8 Jul. 2016); Renner, S., Götz, L. Prehn, S. and Glauben, T. (2014), 'The influence of infrastructure on regional wheat trade in Russia: A gravity model approach', paper for presentation at the EAAE 2014 Congress 'Agri-Food and Rural Innovations for Healthier Societies', 26–29 August 2014, Ljubljana, Halle: Leibniz-Institute for Agricultural Development in Transition Economies (IAMO), http://ageconsearch.umn.edu/bitstream/182840/2/Renner_et_al__2014_EAAE_Poster_Paper_July_1_3.pdf (accessed 8 Jul. 2016).

[100] Glauben, T., Belyaeva, M., Bobojonov, I., Djuric, I., Götz, L., Hockmann, H., Müller, D., Perekhozhuk, O., Petrick, M., Prehn, S., Prishchepov, A., Renner, S. and Schierhorn, F. (2014), *Eastern breadbasket obstructs its market and growth opportunities*, IAMO Policy Brief No. 16, April 2014, http://www.iamo.de/fileadmin/documents/IAMOPolicyBrief16_en.pdf (accessed 8 Mar. 2017).

logistics costs in Ukraine are 40 per cent higher than in Western Europe.[101] Costs are even higher in Russia and Kazakhstan; because of this, where possible, exports from both countries leave via deep-water ports in Ukraine and Estonia (where competition for capacity is less intense and rail freight rates are lower).[102]

A combination of rising exports and underinvestment is putting infrastructure in the Black Sea region under growing strain

According to Gazprombank, part-owned by Russian energy giant Gazprom, upgrading and expanding Russia's infrastructure to maintain economic growth would require US$25–40 billion in private investment by 2020, of which 70 per cent would be needed for transport networks.[103] Ukraine, meanwhile, requires investment of at least US$5 billion in storage facilities and US$1.2 billion in new railway rolling stock by 2023.[104] In Kazakhstan, businesses have identified limited transport infrastructure as the key obstacle to expanding agricultural production.[105] In addition, the whole region has suffered from underinvestment in inland waterways,[106] despite their potential to unburden the creaking railways and to move large volumes of goods at relatively low cost.

Overall, this combination of rising exports and underinvestment is putting infrastructure in the Black Sea region under growing strain. While the region's ports and railways have recently attracted investment from major agribusinesses, including US firms Cargill and Bunge,[107] government funding for broader infrastructural upgrading is likely to remain limited owing to budget deficits, high levels of public debt and lower oil prices.[108] Mismanagement and corruption also limit prospects for a major, high-quality infrastructure development programme. More importantly still, the ongoing conflict in Ukraine perpetuates a high-risk environment for new investments.

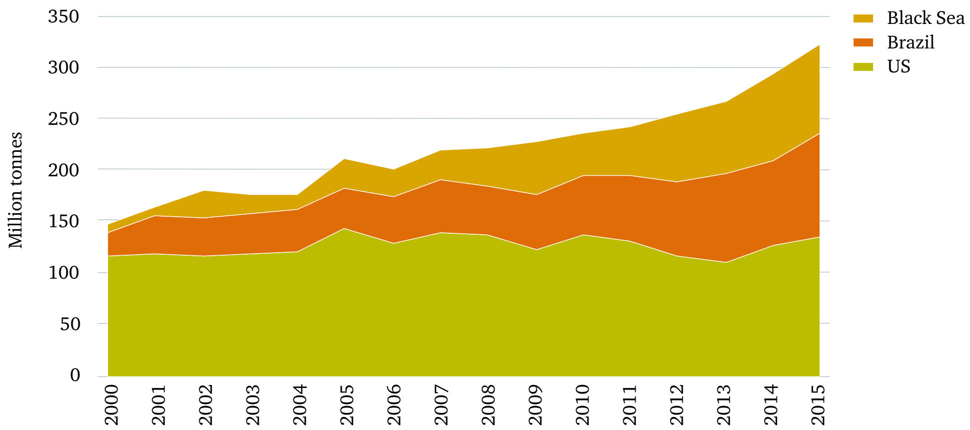
2.2.2 Shifting dynamics

The dramatic rise of Brazilian and Black Sea producers has led to a steady reduction in the US share of global grain exports,[109] and a corresponding decline in the global food system's dependency on US inland and coastal chokepoints. The flipside is that

[101] World Bank (2015), *Shifting into Higher Gear: Recommendations for Improved Grain Logistics in Ukraine*, Report No: ACS15163, Washington, DC: World Bank Group, http://documents.worldbank.org/curated/en/2015/09/25016728/shifting-higher-gear-recommendations-improved-grain-logistics-ukraine (accessed 28 Apr. 2017).
[102] USDA FAS (2011), *Russian Federation: Overview of Russian Grain Port Capacity and Transportation*, GAIN Report Number RS1149, https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Overview%20of%20Russian%20Grain%20Port%20Capacity%20and%20Transportation_Moscow_Russian%20Federation_11-3-2011.pdf (accessed 28 Apr. 2017).
[103] Ganelin, M. and Vasin, S. (2014), 'Russian infrastructure: A big ship sails far', industry report, Gazprombank, 15 July 2014, http://www.gazprombank.ru/upload/iblock/d4c/gpb_russian%20infrastructure_eng_150714.pdf (accessed 16 Aug. 2016).
[104] European Bank for Reconstruction and Development (2015), 'EBRD and Ukraine's agriculture sector partner for reform', 21 May 2015, http://www.ebrd.com/news/2015/ebrd-and-ukraines-agriculture-sector-partner-for-reform.html (accessed 16 Aug. 2016).
[105] OECD (undated), *Kazakhstan: Sector Competitiveness Strategy,* Competitiveness and Private Sector Development report, Eurasia Competitiveness Programme, https://www.oecd.org/globalrelations/47014312.pdf (accessed 17 Aug. 2016).
[106] Deloitte (undated), *Infrastructure & PPP in Ukraine*, InvestUkraine report, http://ccipu.org/it/argomenti/infrastructure (accessed 17 Aug. 2016); Ganelin, M., Yakovlev, Y. and Tayts, M. (2015), *Russian Infrastructure: To build or not to build – that is the question*, industry report, Gazprombank, 3 July 2015, http://www.gazprombank.ru/upload/iblock/0ba/GPB_Infrastructure_update_030715.pdf (accessed 16 Aug. 2016).
[107] Reuters (2016), 'Cargill to invest $100 mln in Ukraine grain terminal', 24 February 2016, http://www.reuters.com/article/grains-ukraine-terminal-idUSL8N1631LC (accessed 18 Aug. 2016); *Business Ukraine* magazine (2016), 'Ukrainian agriculture infrastructure: US giant Bunge invests USD 280 million into the Ukrainian breadbasket', 8 July 2016, http://bunews.com.ua/investment/item/ukrainian-agriculture-infrastructure-bunge-invests-usd-280-million-into-the-ukrainian-breadbasket (accessed 8 Aug. 2016).
[108] Ganelin, Yakovlev and Tayts (2015), *Russian Infrastructure: To build or not to build – that is the question*; Ganelin and Vasin (2014), 'Russian infrastructure: A big ship sails far'.
[109] US exports of wheat, maize, rice and soybean as a proportion of global exports have declined from 33 per cent in 2000 to 22 per cent in 2015 – Chatham House (2017), resourcetrade.earth.

dependency on Brazilian and Black Sea coastal and inland chokepoints has increased. Between 2000 and 2015, Brazil's share of global wheat, maize, rice and soybean exports rose from 6 per cent to 17 per cent; in the Black Sea, the increase was from 2 per cent to 14 per cent (see Figure 18).

Figure 18: Exports of maize, wheat, rice and soybean from the US, Brazil and Black Sea region, 2000–15



Sources: Chatham House Maritime Analysis Tool; Chatham House (2017), resourcetrade.earth.

2.3 Trends and changes in the transport sector and food technology

This section considers how a shift in the nature of trade and transport, and the advancement of disruptive technologies, could change the outlook for food production and trade.

2.3.1 Emerging routes

The Arctic is by far the most-discussed alternative shipping route. In theory, it offers the prospect of new trade channels as climate change melts sea ice and opens up a Northern Sea Route (NSR). Use of the NSR could reduce sailing time between northwestern Europe and northeast Asia by 44 per cent, with a 20–30 per cent saving in transport costs.[110] A viable NSR would avoid both the Panama Canal and passage via the Mediterranean, Middle East and Strait of Malacca, though it could also result in the Bering Strait emerging as a new chokepoint. At its narrowest point, the strait forges a 90-km channel between mainland Russia to the west and Alaska to the east, punctuated by Russia's Diomede Islands.[111] The strait is already an important access point for oil and gas operations in the Chukchi and Beaufort seas, and for the Red Dog

[110] Aksenov, Y., Popova, E. E., Yool, A., Nurser, A. J. G., Williams, T. D., Bertino, L. and Bergh, J. (2016), 'On the future navigability of Arctic sea routes: High-resolution projects of the Arctic Ocean and sea ice', *Marine Policy*, 75: 300–17, doi: 10.1016/j.marpol.2015.12.027 (accessed 8 Jul. 2016).
[111] Brigham, L., Cerne, M., Cole, K., Durham, N., Fish, A., Johnson, C., McCammon, M., Meehan, R., Montoya, S., Newbury, T., Overland, J., Pawlowski, R., Sheffield, G. and Wang, M. (undated), 'Bering Strait Region Case Study', http://www.institutenorth.org/assets/images/uploads/files/5.5-Bering-Strait-Region-Case-Study.pdf (accessed 29 Mar. 2017).

zinc and lead mine in Alaska.[112] Commercial activity is rising: between 2008 and 2012, the number of large vessels transiting the strait more than doubled.[113]

The Northwest Passage (NWP), skirting the northernmost coastline of Canada, offers a second potential Arctic trading route. It could cut the sailing distance between the US east coast and East Asia by up to 20 per cent, and between northwestern Europe and Asia by up to 30 per cent.[114]

Alternative shipping routes have been proposed that would ease the pressure on today's chokepoints, but each depends on the development of huge infrastructure projects with significant environmental and social risks

Neither the NSR nor the NWP is expected to be a viable option for bulk vessels until 2050 at the earliest, however, and doubts remain over the degree to which commercial traders would accept the navigational risks.[115] Even with a significant increase in Arctic shipping, the importance of South American and Black Sea food exports in meeting future Asian demand growth – together with the concentration of fertilizer capacity in and around Eastern Europe and the MENA region – is such that the Mediterranean and Arabian chokepoints will play a critical role for decades to come.

Other alternative shipping routes have been proposed that would ease the pressure on today's chokepoints, but each depends on the development of huge infrastructure projects with significant environmental and social risks. China is the key potential provider of finance to such projects, which include the following:

- **The interoceanic railway across Brazil and Peru.** This would create a new trans-Pacific export channel for soybean grown in southern Brazil and the increasingly productive agricultural regions of Argentina and Paraguay. Effectively, the railway would open up an alternative to current routes from Brazilian ports on the Atlantic coast, instead enabling soybean shipments to be transported by rail to the Peruvian coast and from there directly across the Pacific to Asian markets.[116] Preliminary estimates suggest that the railway, when operational in 2025, could support a third of total soybean exports from Brazil to China.[117] However, the project has already faced numerous objections, from both non-governmental and official bodies, due to the social and

[112] US National Oceanic and Atmospheric Administration (NOAA) (undated), 'Federal and State Offshore Oil & Gas Leases – Beaufort and Chukchi Seas', http://www.nmfs.noaa.gov/pr/pdfs/permits/openwater/map.pdf (accessed 29 Mar. 2017); Brigham et al. (undated), 'Bering Strait Region Case Study'.
[113] Rosen, Y. (2015), 'Polar Code Approval Is Timely for Busy Bering Strait', *Pacific Environment*, https://pacificenvironment.org/in-the-news/polar-code-approval-is-timely-for-busy-bering-strait (accessed 29 Mar. 2017).
[114] Østreng, W., Jørgensen-Dahl, A., Eger, K. M., Mejlænder-Larsen, M., Lothe, L., Fløistad, B. and Wergeland, T. (2013), 'The Northeast, Northwest and Transpolar Passages in Comparison', in Østreng, W., Eger, K. M., Fløistad, B., Jørgensen-Dahl, A., Lothe, L., Mejlaender-Larsen, M. and Wergeland, T. (eds), *Shipping in Arctic Waters: A comparison of the Northeast, Northwest and Trans-Polar Passages,* Springer Praxis Books, doi: 10.1007/978-3-642-16790-4_8 (accessed 18 Aug. 2016).
[115] Smith, L. C. and Stephenson, S. R. (2013), 'New Trans-Arctic shipping routes navigable by midcentury', *PNAS,* 110(13): 4871–2, doi: 10.1072/pnas.1214212110 (accessed 18 Aug. 2016); Hansen, C. O., Gronsedt, P., Graversen, C. L. and Hendriksen, C. (2016), *Arctic Shipping – Commercial Opportunities and Challenges*, CBS Maritime, Copenhagen Business School, https://services-webdav.cbs.dk/doc/CBS.dk/Arctic%20Shipping%20-%20Commercial%20Opportunities%20and%20Challenges.pdf (accessed 18 Aug. 2016); Østreng et al. (2013), 'The Northeast, Northwest and Transpolar Passages in Comparison'; Farré, A. B., Stephenson, S. R., Chen, L., Czub, M., Dai, Y., Demchev, D., Efimov, Y., Graczyk, P., Grythe, H., Keil, K., Kivekäs, N., Kumar, N., Kiu, N., Matelenok, I., Myksvoll, M., O'Leary, D., Olsen, J., Pavithran, S. A. P., Petersen, E., Raspotnik, A., Ryzhov, I., Solski, J., Suo, L., Troein, C., Valeeva, V., van Rijckevorsel, J. and Wighting, J. (2014), 'Commercial Arctic shipping through the Northeast Passage: routes, resources, governance, technology, and infrastructure', *Polar Geography* 37(4): 298–324, doi: 10.1080/1088937X.2014.965769 (accessed 8 Jul. 2016); Aksenov et al. (2016), 'On the future navigability of Arctic sea routes' (accessed 28 Apr. 2017).
[116] Ortiz, F. (undated), 'Brazil, Peru and China and the Inter-oceanic Dream', *Diálogo Chino,* http://dialogochino.net/china-is-part-of-an-interoceanic-dream-between-brazil-and-peru/ (accessed 21 Mar. 2017); Elliott, L. (2014), 'New farming frontiers in Latin America', *Financial Times,* 4 July 2014, http://blogs.ft.com/beyond-brics/2014/07/04/new-farming-frontiers-in-latin-america (accessed 21 Mar. 2017).
[117] Leal, M. (2016), 'Fears raised over new Amazon railroad', *China Dialogue,* 31 August 2016, https://www.chinadialogue.net/article/show/single/en/9200-Fears-raised-over-new-Amazon-railroad (accessed 5 Apr. 2017).

environmental risks of completing a major infrastructure project in the Amazon basin.[118]

- **The proposed Nicaraguan Canal megaproject.** This would connect the Caribbean (and thus the Atlantic) with the Pacific – relieving pressure on the Panama Canal. However, construction stalled in 2015, a year after the project started, following protests from indigenous groups and NGOs concerned about environmental impacts, and amid apparent financial difficulties.[119]
- **The Kra Canal.** This is one of the trade corridors planned as part China's 'Belt and Road' initiative. The Kra Canal would cut across the Malay Peninsula in southern Thailand and so provide an alternative to the Strait of Malacca for east–west trade. Singapore's continued prominence as a trans-shipment hub is nevertheless likely to dampen the impact of the Kra Canal on traffic through the Strait of Malacca.

2.3.2 Shipping trends

Our estimates of flows passing through maritime chokepoints are based in part on the assumption that global trade in grain and fertilizers uses dry bulk vessels chartered for single, point-to-point voyages. This contrasts with container shipping, where vessels follow predetermined routes with numerous pick-up and drop-off ports of call.[120] Currently only a small proportion of grain trade is containerized. Such trade primarily involves high-value commodities for which shipment traceability is important, or small shipments for which the use of a dry bulk vessel would incur disproportionately high freight costs and long storage times.[121]

Standard practice could change in the coming years, however, as containerization of dry bulk goods is on the rise. Where export volumes are low, for example from emerging maize and wheat producers in sub-Saharan Africa, containerized parcel services already enable several exporters to share the capacity of a given vessel when none can afford to charter the entire ship.[122] Small-scale producers in sub-Saharan Africa might be able to harness these services to export their goods using the continuous flow of empty containers returning to Asia.[123] This could conceivably support rapid growth in 'South–South' trade between emerging markets, reducing the dependence of Asian importers on European, North American and South American producers, and on the trade chokepoints that punctuate these supply chains.

[118] Ibid.
[119] Al Jazeera America (2015), 'Controversial Nicaragua canal project delayed', 25 November 2015, http://america.aljazeera.com/articles/2015/11/25/controversial-nicaragua-canal-project-delayed.html (accessed 21 Mar. 2017); Morris, D. Z. (2016), 'Why China and Nicaragua's Canal Project is Floundering', *Fortune*, http://fortune.com/2016/02/29/china-nicaragua-canal (accessed 21 Mar. 2017).
[120] Christiansen, M., Fagerholt, K. and Ronen, D. (2004), 'Ship Routing and Scheduling: Status and Perspectives', *Transportation Science*, 38(1): pp. 1–18 (accessed 28 Apr. 2017).
[121] Lirn, T. T. C. and Wang, J.-D. (2016), 'The Determinants of Containerised Grain Shipping', in Pawar, K. S., Rogers, H., Potter, A. and Naim, M. (eds), *Developments in Logistics and Supply Chain Management: Past, Present and Future,* pp. 215–230, Basingstoke: Palgrave Macmillan UK, doi: 10.1057/9781137541253_19 (accessed 10 Apr. 2017); Munro, E. (2011), 'Containers Move High-Value Exports – When do Containers Work Best for the Grain Buyer and the Grower?', *Corn & Soybean Digest*, 1 September 2011, http://cornandsoybeandigest.com/issues/containers-move-high-value-exports-when-do-containers-work-best-grain-buyer-and-grower (accessed 10 Apr. 2017).
[122] Munro (2011), 'Containers Move High-Value Exports – When Do Containers Work Best For the Grain Buyer and the Grower?'.
[123] Ocean Shipping Consultants Ltd. (2008), *Beyond the Bottlenecks: Ports in Sub-Saharan Africa*, background paper for World Bank and SSATP, http://www.eu-africa-infrastructure-tf.net/attachments/library/aicd-background-paper-8-ports-sect-summary-en.pdf (accessed 21 Mar. 2017).

2.3.3 Disruptive technologies and trends in the food system

Over the past decade rapid technological change has occurred, in the food sector and beyond, that could transform the global food system. Game-changing breakthroughs in crop science and genome-editing, and efficiency improvements in transport and logistics, have coincided with a shift in consumption trends around the world.

Each of these factors has the potential to disrupt current patterns of production, demand and trade, lessening dependence on today's trade networks and chokepoints, and opening up new opportunities for managing the risk of food shocks (see Box 4).

Box 4: Potential game-changing disruptions in the food system

New methods of **environment-controlled agriculture** are emerging that limit resource inputs and protect against climate damage, disease and pests. Hydroponics (water-based systems that do not require soil and that deliver optimal supplies of nutrients to plants through fortified water solutions), aeroponics (soil-less systems, using minimal water, in which plants are fed nutrient-rich solutions at timed intervals) and aquaponics (combining aquaculture and hydroponics to cultivate fish and plants in one closed-loop system) are already in use to grow fruit and vegetables.

Use of such systems is expected to expand rapidly.[124] They allow for food to be produced in urban and peri-urban centres where demand is high, lessening dependence on rural–urban transport connections and, potentially, on imported food. Scaling up these systems could help dampen the rapid rise in demand for imported food that has been driven by urbanization, particularly in Asia, in recent years. In the near to medium term, environment-controlled agriculture could provide a buffer for urban populations in the event that imported supply is disrupted.

With rapidly falling costs, **genome-editing** technologies such as CRISPR could soon be employed across the globe on 'orphan crops' such as sorghum and millet, as well as on cash crops such as soybean and maize.[125] This would enable farmers to diversify production and would support yield growth in regions where agro-climatic conditions have, until now, stunted expansion and intensification.

Alternative means of fertilization are under development. Enabling nitrogen fixation by grain crops could radically reduce modern agriculture's dependence on artificial fertilizers.[126] Research is under way into two distinct approaches to doing so. One uses microbial-based products in which bacteria and fungi serve as natural fertilizers, insecticides and fungicides. Major agribusiness and pharmaceutical firms, including Bayer, DuPont and Monsanto, have invested in research and development around these products;[127] the Bill & Melinda Gates Foundation is also funding research in sub-Saharan Africa.[128] Should start-up costs fall, these

[124] Business Wire (2016), 'Global Hydroponics Market 2015-2020 – Market value is anticipated to grow from $19.95 billion to $27.33 billion in 2020 – Research and Markets', 11 August 2016, http://www.businesswire.com/news/home/20160811005565/en/Global-Hydroponics-Market-2015-2020---Market-anticipated (accessed 24 Mar. 2017); pH Hydro (2014), 'Aeroponics 101: Facts about soilless growing technology', PowerHouse Hydroponics, 24 July 2014, http://www.powerhousehydroponics.com/aeroponics-101-facts-about-soilless-growing-technology/ (accessed 24 Mar. 2017); Challen, J. (2015), 'Get ready for organic indoor vertical farms', *Future Ag*, 12 November 2015, http://futureag.info/news/get-ready-for-organic-indoor-vertical-farms (accessed 24 Mar. 2017).
[125] Ledford, H. (2015), 'CRISPR, The Disruptor', *Nature*, 522(7554): 20–24, doi: 10.1038/522020a (accessed 24 Mar. 2017).
[126] Dent, D. and Cocking, E. (2017), 'Establishing symbiotic nitrogen fixation in cereals and other non-legume crops: The Greener Nitrogen Revolution', *Agriculture & Food Security*, 6:7, doi: 10.1186/s40066-016-0084-2 (accessed 24 Mar. 2017).
[127] Zhang, S. (2016), 'Good riddance, chemicals: microbes are farming's hot new pesticides', *Wired*, 21 March 2015, https://www.wired.com/2016/03/good-riddance-chemicals-microbes-farmings-hot-new-pesticides (accessed 24 Mar. 2017).
[128] The Conversation (2017), 'Why microbes are key to solving Africa's food security crisis', 30 January 2017, https://theconversation.com/why-microbes-are-key-to-solving-africas-food-security-crisis-71719 (accessed 24 Mar. 2017).

Refrigeration allows for strategic stockpiling to regulate supply over the course of a season or year, and to create a buffer against sudden supply shocks

technologies could offer a low-cost alternative to imported fertilizer, which is prohibitively expensive for many small-scale producers in developing countries.[129]

The other alternative approach to fertilization involves experimental genome-editing technologies that are designed to mimic in grains the nitrogen-fixing capacity of legumes. Research in this area is also receiving Gates Foundation support. If hoped-for advances are made in the coming years, the gains in crops yields in developing countries could be massive.[130]

Industrial disruptions in the fertilizer sector may also occur as use of renewable energy sources takes off. Assuming that the environment-controlled agriculture, genome-editing and alternative fertilization technologies mentioned above are not deployed at scale in the near term, renewable energy could transform the geo-economics of nitrogen fertilizer production. The use of electricity from wind power, biogas and woody biomass has the potential to decentralize ammonia production and extricate countries from globalized supply chains.[131, 132] Countries that are investing heavily in solar and/or wind power – such as Brazil, China, India, Morocco, the US and Western European countries[133] – could ramp up domestic production, precipitating the localization of fertilizer markets. This would reduce the dependence of global ammonia supply on a handful of major production centres.

While not a new technology, **cold-chain logistics and cold storage**, if deployed at scale, could be a game-changer in developing countries – particularly in remote areas – where the risk of damage to crops and/or stocks from weather is high.[134] As well as reducing waste along supply chains, refrigeration allows for strategic stockpiling to regulate supply over the course of a season or year, and to create a buffer against sudden supply shocks.[135]

Interest in **alternative protein products**, including cultured meat, is mounting.[136] Media attention around the world's first lab-grown burger and around vegetarian imitations

[129] Vance, C. P. (2001), 'Symbiotic Nitrogen Fixation and Phosphorus Acquisition. Plant Nutrition in a World of Declining Renewable Resources', *Plant Physiology*, 127(2): 390–97, doi: 10.1104/pp.010331 (accessed 24 Mar. 2017).
[130] Stokstad, E. (2016), 'The nitrogen fix', *Science*, 353(6305): 1225–1227, doi: 10.1126/science.353.6305.1225 (accessed 24 Mar. 2017).
[131] Tunå, P., Hulteberg, C. and Ahlgren, S. (2013), 'Techno-economic assessment of nonfossil ammonia production', *Sustainability*, 33(4): 1290–1297, doi: 10.1002/ep.11886 (accessed 24 Mar. 2017).
[132] For a discussion of the potential limitations of using woody biomass for power, see Brack, D. (2017), *The Impacts of the Demand for Woody Biomass for Power and Heat on Climate and Forests*, Research Paper, London: Royal Institute of International Affairs, https://www.chathamhouse.org/publication/impacts-demand-woody-biomass-power-and-heat-climate-and-forests (accessed 10 Apr. 2017).
[133] Renewable Energy Policy Network for the 21st Century (2016), *Renewables 2016 – Global Status Report*, http://www.ren21.net/wp-content/uploads/2016/06/GSR_2016_Full_Report.pdf (accessed 25 Apr. 2017).
[134] Winkworth-Smith, C. G., Foster, T. J. and Morgan, W. (2015), *The Impact of Reducing Food Loss in the Global Cold Chain,* Nottingham: University of Nottingham, http://naturalleader.com/wp-content/uploads/2016/04/UTC-Nottingham-Report_3-30_FINAL.pdf (accessed 24 Mar. 2017).
[135] Kitinoja, L. (2013), *Use of cold chains for reducing food losses in developing countries,* Postharvest Education Foundation, White Paper No. 13-03, http://postharvest.org/Use%20of%20cold%20chains%20PEF%20white%20paper%2013-03%20final.pdf (accessed 24 Mar. 2017).
[136] Loizos, C. (2015), 'Impossible Foods Raises a Whooping $108 Million for Its Plant-Based Burgers', TechCrunch, 6 October 2015, https://techcrunch.com/2015/10/06/impossible-foods-raises-a-whopping-108-million-for-its-plant-based-burgers/ (accessed 28 Apr. 2017); Castelvecchi, D. (2013), 'Researchers put synthetic meat to the palate test', *Nature*, 5 August 2013, http://blogs.nature.com/news/2013/08/researchers-put-synthetic-meat-to-the-palate-test.html (accessed 28 Apr. 2017); Stone, M. (2015), 'How a startup that makes fake meat from plants caught the attention of Bill Gates and the founders of Twitter', *Business Insider UK*, 15 August 2015, http://uk.businessinsider.com/how-a-startup-that-makes-fake-meat-from-plants-caught-the-attention-of-bill-gates-and-the-founders-of-twitter-2015-7 (accessed 28 Apr. 2017); Wagstaff, K. (2012), 'Billionaire Peter Thiel's Latest Investment: 3D-Printed Meat', *Time*, 16 August 2012, http://techland.time.com/2012/08/16/billionaire-peter-thiels-latest-investment-3d-printed-meat (accessed 28 Apr. 2017); Ortenberg, C. (2016), 'Big Infestment: Insect Protein Brand Exo Lands $4 Million Round', Project Nosh, 8 March 2016, https://www.projectnosh.com/news/2016/big-infestment-insect-protein-brand-exo-lands-4-million-round (accessed 28 Apr. 2017).

Continued growth in Asian demand for meat would put an increasing strain on the inland and coastal chokepoints of the US and Brazil, as well as on the maritime chokepoints linking them to Asian markets

of meat products[137] reflects interest in a rapidly evolving sector with the potential to disrupt agribusiness incumbents. Meat alternatives are already on the market in China and the US, with consumption expected to grow rapidly in global markets.[138] Were this nascent industry to materially reduce demand for meat and dairy products, the vast volumes of soybean and maize grown and traded to support livestock production could decline dramatically.

While not strictly a technological disruption, the **nutrition transition** unfolding across many middle- and low-income countries is having an appreciable impact on the shape of global grain trade. Rapidly rising demand for protein-rich and calorie-intense foods, most notably meat and dairy products, is driving up demand for grain and fertilizer inputs to support intensive livestock production systems in middle- and high-income countries.[139] Global demand for meat and dairy products is expected to rise by 76 per cent and 65 per cent respectively by 2050, with China accounting for a significant share of this growth.[140] The boom in pig and poultry production in China has already transformed the global soybean market over the past 15 years.[141] It has prompted a dramatic rise in soybean exports from South America, the US and Europe, shipped through the Strait of Malacca and Panama Canal. Continued growth in Asian demand would put an increasing strain on the inland and coastal chokepoints of the US and Brazil, as well as on the maritime chokepoints linking them to Asian markets. On the other hand, if demand plateaus sooner than expected – in response to government efforts to limit meat intake, for example[142] – soybean exports from Brazil and the US could diminish.

Disruptive technologies will also create opportunities for more effective and comprehensive risk management in the food system. **Machine learning** and the **Internet of Things** will likely have a transformative impact on risk monitoring and forecasting,[143] allowing for more expansive and accurate climate predictions and for the modelling of possible disruptions and their cascade effects.[144]

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[137] Kauffmann, J. (2017), '"Veggie burger that bleeds" set to take on US market', *San Francisco Chronicle*, 22 March 2017, http://www.sfchronicle.com/bayarea/article/Veggie-burger-that-bleeds-set-to-take-on-11020144.php#photo-11391777 (accessed 24 Mar. 2017).
[138] Liddle, J. (2016), 'Meat's Off the Menu: Exploring Opportunities for Meat Alternatives in China', *China Briefing,* 15 July 2015, http://www.china-briefing.com/news/2016/07/15/exploring-opportunities-for-meat-alternatives-in-china.html (accessed 24 Mar. 2017); Strom, S. (2016), 'Plant-Based, the Beyond Burger Aims to Stand Study Among Meat', *New York Times*, 22 May 2016, https://www.nytimes.com/2016/05/23/business/plant-based-the-beyond-burger-aims-to-stand-sturdy-among-meat.html (accessed 24 Mar. 2017); Lux Research (2015), 'Alternative Proteins to Claim a Third of the Market by 2054', http://www.luxresearchinc.com/news-and-events/press-releases/read/alternative-proteins-claim-third-market-2054 (accessed 24 Mar. 2017).
[139] Erb, K.-H., Mayer, A., Kastner, T., Sallet, K.-E. and Haberl, H. (2012), *The Impact of Industrial Grain-Fed Livestock Production on Food Security: an extended literature review*, commissioned by Compassion in World Farming, The Tubney Charitable Trust and World Society for the Protection of Animals, https://www.ciwf.org.uk/includes/documents/cm_docs/2012/t/the_impact_of_industrial_grain_fed_livestock_production_on_food_security_2012.pdf (accessed 25 Apr. 2017).
[140] Bailey, Froggatt and Wellesley (2014), *Livestock – Climate Change's Forgotten Sector* (accessed 31 Mar. 2017).
[141] Lee, B., Preston, F., Bailey, R., Lahn, G. and Kooroshy, J. (2012), *Resources Futures*, Chatham House Report, https://www.chathamhouse.org/sites/files/chathamhouse/public/Research/Energy%2C%20Environment%20and%20Development/1212r_resourcesfutures.pdf (accessed 31 Mar. 2017).
[142] Froggatt, A. and Wellesley, L. (2016), 'China Shows Way with New Diet Guidelines on Meat', Chatham House Expert Comment, 21 June 2016, https://www.chathamhouse.org/expert/comment/china-shows-way-new-diet-guidelines-meat (accessed 18 Jun. 2017).
[143] Manyika, J., Chui, M., Bughin, G., Dobbs, R., Bisson, P. and Marrs, A. (2013), *Disruptive technologies: Advances that will transform life, business, and the global economy,* McKinsey Global Institute, http://www.mckinsey.com/business-functions/digital-mckinsey/our-insights/disruptive-technologies (accessed 24 Mar. 2017).
[144] Kingdon, A., Giles, J. R. A. and Lowndes, J. (2017), 'Future of technology in NERC data models and informatics: outputs from InformaTEC', Geological Society, London, Special Publication, http://sp.lyellcollection.org/content/408/1/245.short (accessed 5 Apr. 2017).

2.4 Conclusions

As international markets become increasingly integral to food security, so too do the transport networks and chokepoints on which global trade depends: the share of internationally traded grain and fertilizer has increased since 2000, and this trend looks set to continue. Certain countries – most notably those of the Gulf Cooperation Council (GCC) and in the Black Sea region – are almost wholly dependent on one or several of the eight maritime chokepoints for access to international markets.

Despite their systemic importance, these trade junctures have received little attention from policymakers and analysts within the context of national and/or global food security. Rising throughput volumes, coupled with a lack of investment – particularly in the inland and coastal chokepoints of the US, Brazil and Black Sea region – are exerting increasing strain on this infrastructure, rendering it more vulnerable to disruption.

In the following chapter, we explore the range of hazards – climatic, security-related and institutional – that threaten the operation of the 14 chokepoints, and consider how these hazards may evolve in the coming years.

3. Hazards to Chokepoint Operation

Key points

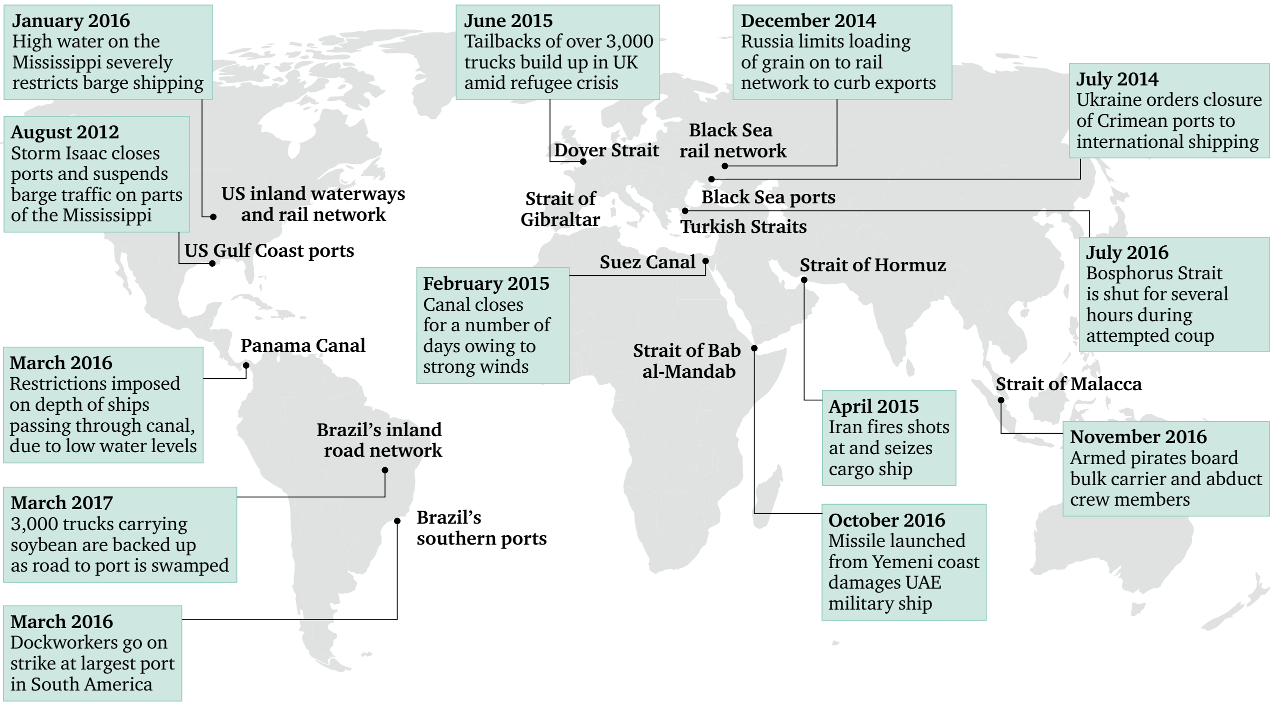
- The potential drivers of disruption span slow-onset climate impacts, extreme climate events, institutional failure, political interference, physical attack and cyberattack.
- Major disruptions to food system chokepoints are rare but not unprecedented, and are likely to become more frequent and severe as climate impacts and resource insecurity worsen. Climate change is a hazard multiplier and will likely aggravate underlying socioeconomic and political stresses.
- Disruption of any one chokepoint is unlikely to have a serious impact on global food security, but the compounding effect of concurrent trade dislocations at multiple chokepoints could be significant. In a climate-changed world, the risk of such concurrent dislocations is likely to rise.
- Only one of the 14 chokepoints (the Strait of Gibraltar) has been free from disturbance over the past 15 years; the most at-risk chokepoints are the US inland transport corridors, the Black Sea railways and ports, and the ports of southern Brazil.
- The South China Sea could become a de facto chokepoint in the near future.

Food trade chokepoints are exposed to diverse threats of varying severity. In many instances, these threats are not hypothetical but real, generating discernible impacts in terms of transport costs and delays. In isolation, disruption of any one chokepoint is unlikely to have a serious impact on global food security: in the wake of a storm, for example, the recovery period tends to be fairly short, and in most cases alternative sources of supply or trade routes exist that allow for the system to recalibrate temporarily. But the cumulative effect of concurrent trade dislocations at multiple major chokepoints would threaten to interrupt strategic supply routes, undermine system efficiency and amplify price spikes.

3.1 Disruptive threats to food system chokepoints

Disruptive threats to food system chokepoints broadly fall under three categories: weather and climate hazards; security and conflict hazards; and political and institutional hazards. Major disruptions are rare, but are not unprecedented (see Figure 19). Key threats to maritime, coastal and inland chokepoints – and examples of their impact – are discussed below.

Figure 19: Examples of recent chokepoint disruptions



Source: Authors' analysis; further details of each disruption, together with references, may be found in Annex 2.

3.1.1 Weather and climate hazards

Weather poses both acute and chronic threats to the smooth operation of chokepoints. The cumulative impacts of high and low temperatures, heavy rainfall, drought, high winds, storms and storm surges can reduce the efficiency, integrity and capacity of transport infrastructure, potentially leading to temporary but severe disruptions.

Weather poses both acute and chronic threats to the smooth operation of chokepoints

Climate change will have a multiplying effect on weather-related hazards. While changes in average temperature and rainfall are expected to unfold gradually – and may lessen weather risks in certain regions – these changes are predicted to have a compounding and non-linear effect in terms of their contribution to extreme weather conditions and acute events.[145] By way of example, researchers estimate that a sea-level rise of one metre would render a one-in-100-year flood event in the Indian city of Kolkata 1,000 times more likely.[146]

Over time, weather-induced wear and tear heightens infrastructural vulnerability to extreme climate events, which themselves are expected to intensify in severity and

[145] Trenberth, K. E., Fasullo, J. T. and Shepherd, T. G. (2015), 'Attribution of climate extreme events', *Nature Climate Change*, 5: 725–30, doi: 10.1038/nclimate2657 (accessed 24 Apr. 2017); Hassol, S. J., Torok, S., Lewis, S. and Luganda, P. (2016), '(Un)Natural Disasters: Communicating Linkages Between Extreme Events and Climate Change', World Meteorological Organization, Bulletin No. 65(2), https://public.wmo.int/en/resources/bulletin/unnatural-disasters-communicating-linkages-between-extreme-events-and-climate (accessed 24 Apr. 2017).
[146] King, D., Schrag, D., Dadi, Z., Ye, Q. and Ghosh, A. (2015), *Climate Change: A Risk Assessment*, Centre for Science and Policy, University of Cambridge, http://www.csap.cam.ac.uk/projects/climate-change-risk-assessment (accessed 24 Apr. 2017).

frequency as climate change progresses.[147] Shorter intervals between extreme events may make both routine maintenance and disaster recovery more challenging, and limit the time available to prepare for the next shock.[148] In the absence of efficient and robust response and recovery plans, each high-impact event may have a compounding impact upon the next, undermining both the short-term and long-term integrity of physical structures.

3.1.1.1 Rainfall extremes

Heavy rainfall and surface flooding pose a risk to port infrastructure and storage facilities. Impacts will be greater where options for shifting trade to other modes of transport and export routes are limited. For example, in the case of disruption to US waterways, congestion on roads and railways could limit the scope to transport grain exports by truck or train. Flooding and drought as a result of climate change are forecast to bring more regular interruptions to trade along US transport corridors;[149] the 2012 drought that caused water levels along the Mississippi to fall to record lows severely delayed the delivery of fertilizers to farmers in the Midwest.[150] Extremes in rainfall also pose an operational hazard to man-made canals: a particularly strong El Niño event in the spring of 2016 brought long periods of dry weather to Central America, causing water levels to drop in the Gatún and Miraflores lakes either side of the Panama Canal and leading to the introduction of depth restrictions that affected nearly a fifth of vessels using the canal.[151]

3.1.1.2 Sea-level rise

Climate change will result in higher sea levels due to thermal expansion of the oceans and meltwater from glaciers and ice sheets. Considerable uncertainty surrounds the modelling of sea levels, but the best available science anticipates a global rise of 0.44–0.74 metres above 1986–2005 levels by 2100.[152] It is important to note that this may be an underestimate, given the potential for non-linearities and tipping points to create faster change than many models currently capture.[153] Higher sea levels will lead to more damaging storm surges that threaten port and coastal structures. The port of New Orleans on the US Gulf Coast and the Dutch port of Rotterdam, northeast of the Dover Strait, are among the most exposed to storm

[147] World Bank (2013), *Turn Down the Heat: Climate Extremes, Regional Impacts, and the Case for Resilience*, http://www.worldbank.org/en/topic/climatechange/publication/turn-down-the-heat-climate-extremes-regional-impacts-resilience (accessed 29 Mar. 2017); Coumou, D. and Rahmstorf, S. (2012), 'A decade of weather extremes', *Nature Climate Change,* 2: 491–496, doi: 10.1038/nclimate1452 (accessed 29 Mar. 2017).
[148] OECD (2016), *The role of government in making infrastructure investment climate resilient: draft survey of current practices*, Working Party on Climate, Investment and Development, 23–24 February 2016, http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=ENV/EPOC/WPCID(2016)2&docLanguage=En (accessed 8 Mar. 2017).
[149] Gordon et al. (2015), *Heat in the Heartland* (accessed 6 Jul. 2016).
[150] Schwartz, J. (2012), 'After Drought, Reducing Water Flow Could Hurt Mississippi River Transport', *New York Times,* 26 November 2012, http://www.nytimes.com/2012/11/27/us/hit-by-drought-mississippi-river-may-face-more-challenges.html (accessed 27 Mar. 2017).
[151] Canal de Panamá (2016), 'To Mitigate Effects of "El Niño" Phenomenon, the Panama Canal Announces Draft Restrictions to Transiting Vessels', 21 March 2016, http://www.pancanal.com/eng/pr/press-releases/2016/03/22/pr578.html (accessed 2 May 2017).
[152] Taking the median values of RCP2.6 and RCP8.5 scenarios for global mean sea level rise in 2100 – Church, J. A., Clark, P. U., Cazenave, A., Gregory, J. M., Jevrejeva, S., Levermann, A., Merrifield, M. A., Milne, G. A., Nerem, R. S., Nunn, P. D., Payne, A. J., Pfeffer, W. T., Stammer, D. and Unnikrishnan, A. S. (2013), 'Sea Level Change', in Stocker, T. F., Qin. D., Plattner, G.-K., Tignor, M., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V. and Midgley, P. M. (eds) (2013), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge, UK and New York, NY: Cambridge University Press, https://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter13_FINAL.pdf (accessed 6 Apr. 2017).
[153] Benton et al. (2017), *Environmental tipping points and food system dynamics*.

surges and high winds in terms of at-risk asset value and population size,[154] while the integrity of coastal structures in Brazil, including major port areas, is expected to be compromised by climate change impacts on wave height and sea level.[155]

The integrity of coastal structures in Brazil, including major port areas, is expected to be compromised by climate change impacts on wave height and sea level

3.1.1.3 Tropical storms

While storm activity is influenced by a range of factors,[156] available evidence suggests that rising ocean temperatures are likely to bring more frequent and severe storms and tropical cyclones.[157] Stronger storms are likely to combine with higher sea levels to produce more severe storm surges and greater damage to infrastructure.[158] Climate change may bring cyclone activity to the Strait of Hormuz.[159] Meanwhile, ports along the Gulf Coast of the US are already exposed to tropical cyclones.[160] An assessment of the economic risks posed by climate change to US infrastructure envisages up to US$50.6 billion worth of annual coastal storm damage being wrought on Florida's infrastructure within 25 years.[161]

3.1.1.4 Climate change as a hazard multiplier

Climate change is likely to aggravate socioeconomic and political risks. Extreme weather events and more frequent harvest failures are expected to increase human displacement, indirectly amplifying the risks of inter-group violent conflict and civil war by exacerbating conflict drivers such as poverty, economic shocks and localized resource scarcity.[162] As coastlines and maritime borders are redrawn by rising sea levels, the risk of territorial disputes may increase. Climate-induced food supply shortages may prompt the more regular imposition of unilateral trade measures. One preliminary analysis found that a global agricultural production shock that would

[154] Nicholls, R. J., Hanson, S., Herweijer, C., Patmore, N., Hallegatte, S., Corfee-Morlot, J., Château, J. and Muir-Wood, R. (2008), *Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes: Exposure Estimates*, OECD Environment Working Papers, No.1, Paris: OECD Publishing, doi: 10.1787/011766488208 (accessed 8 Jul. 2016).
[155] Magrin, G. O., Marengo, J. A., Boulanger, J.-P., Buckeridge, M. S., Castellanos, E., Poveda, G., Scarano, F. R. and Vicuña, S. (2014), 'Central and South America', in Barros, V. R., Field, C. B., Dokken, D. J., Mastrandrea, M. D., Mach, K. J., Bilir, T. E., Chatterjee, M., Ebi, K. L., Estrada, Y. O., Genova, R. C., Girma, B., Kissel, E. S., Levy, A. N., MacCracken, S., Mastrandrea, P. R. and White, L. L. (eds) (2014), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge, UK and New York, NY: Cambridge University Press, pp. 1499–1566, http://www.ipcc.ch/report/ar5/wg2 (accessed 10 Apr. 2017).
[156] Stocker, T. F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V. and Midgley, P. M. (2013) (eds), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge: Cambridge University Press, http://www.ipcc.ch/report/ar5/wg1 (accessed 10 Apr. 2017).
[157] Coumou, D. and Rahmstorf, S. (2012), 'A decade of weather extremes', *Nature Climate Change,* 2: 491–496, doi: 10.1038/nclimate1452 (accessed 29 Mar. 2017); Knutson, T., McBride, J. L., Chan, J., Emanuel, K., Holland, G., Landsea, C., Held, I., Kossin, J. P., Srivastava, A. K. and Sugi, M. (2010), 'Tropical cyclones and climate change', *Nature Geoscience*, 3: 157–163, doi: 10.1038/ngeo779 (accessed 29 Mar. 2017).
[158] Nicholls, R. J. and Tol, R. S. J. (2006), 'Impacts and responses to sea-level rise: a global analysis of the SRES scenarios over the twenty-first century', *Philosophical Transactions of the Royal Society*, 364(1841), doi: 10.1098/rsta.2006.1754 (accessed 19 Mar. 2017).
[159] Lin, N. and Emanuel, K. (2016), 'Grey swan tropical cyclones', *Nature Climate Change,* 6: 106–111, doi: 10.1038/nclimate2777 (accessed 27 Mar. 2017).
[160] Becker, A., Inoue, S., Fischer, M. and Schwegler, B. (2011), 'Climate change impacts on international seaports: knowledge, perceptions, and planning efforts among port administrators', *Climatic Change*, doi: 10.1007/s10584-011-0043-7 (accessed 8 Jul. 2016).
[161] The Blue Paper (2016), 'Risky Business Report Finds Businesses and Infrastructure in U.S. and Florida Face Significant Risks From Climate Change', 20 May 2016, http://thebluepaper.com/article/risky-business-report-finds-businesses-and-infrastructure-in-u-s-and-florida-face-significant-economic-risks-from-climate-change (accessed 19 Jul. 2016).
[162] IPCC (2014), 'Summary for policymakers', in Field, C. B., Barros, V. R., Dokken, D. J., Mach, K. J., Mastrandrea, M. D., Bilir, T. E., Chatterjee, M., Ebi, K. L., Estrada, Y. O., Genova, R. C., Girma, B., Kissel, E. S., Levy, A. N., MacCracken, S., Mastrandrea, P. R. and White, L. L. (eds), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge: Cambridge University Press, http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/ar5_wgII_spm_en.pdf (accessed 23 May 2017); Rüttinger, L., Smith, D., Stang, G., Tänzler, D. and Vivekananda, J. (2015), *A New Climate for Peace: Taking Action on Climate and Fragility Risks*, independent report commissioned by G7 members, submitted under the German G7 Presidency, https://www.newclimateforpeace.org/#report-top (accessed 23 May 2017).

have been defined as a one-in-100-year event in 1951–2010 could become a one-in-30-year occurrence by 2040, increasing the risk of export bans and food price crises.[163]

3.1.2 Security and conflict hazards

Transnational trade routes for critical resources often involve transit through conflict-affected or weakly governed areas, with the result that certain chokepoints are at risk from instability (see Figure 20). For example, the Suez Canal, Turkish Straits, Strait of Bab al-Mandab, Strait of Hormuz and ports in the Black Sea all border on, or are located in, states for which the Fund for Peace has issued a warning, alert or high alert about the possibility of state failure.[164]

As well as having direct impacts on operations and infrastructure, political and social instability can affect chokepoints indirectly. For example, ongoing conflict has troubled potential investors in the Black Sea;[165] in 2014, foreign direct investment (FDI) in the Black Sea region was less than 2 per cent of GDP, and gross foreign investment had fallen to its lowest level since 2008.[166] Populations displaced by conflict can also disrupt chokepoints. For example, migration across the Dover Strait in 2015 and 2016 caused traffic restrictions and border force strikes, leading to delays and higher transport costs for industry.[167, 168]

3.1.2.1 Armed conflict

Globally, the incidence of armed conflict appears to be in long-term decline: the number of active conflicts worldwide fell from 63 in 2008 to 40 in 2015, though wars have also become more intense.[169] Despite this global trend, it is reasonable to assume that certain regions will remain vulnerable to conflict for the foreseeable future, with implications for the security of particular chokepoints. The risk of conflict in the Middle East will remain, for example, with continued implications for the security of the Arabian chokepoints. Terrorist attacks in Egypt's Sinai Peninsula, to the east of the Suez Canal, are becoming more common. The war in Yemen persists, with little hope for imminent peace. And the risk of armed conflict in Turkey is non-trivial: the country shares borders with conflict-ravaged Syria and Iraq; there has been a recent upsurge in terrorism in the region; and a recent coup attempt and subsequent crackdown in Turkey itself have highlighted concerns about stability. Moreover, the potential for an escalation in tensions between Turkey and Russia remains (see Box 5). Each of these factors has implications for the security of the Turkish Straits.

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163 Bailey et al. (2015), *Extreme weather and resilience of the global food system*.
164 Messner, J. J. (ed.) (2016), *Fragile States Index 2016*, Washington, DC: The Fund for Peace, http://library.fundforpeace.org/library/fragilestatesindex-2016.pdf (accessed 22 Aug. 2016).
165 HighQuest Partners, United States (2010), *Private Financial Sector Investment in Farmland and Agricultural Infrastructure,* OECD Food, Agriculture and Fisheries Working Papers, No. 33, OECD Publishing, http://www.oecd-ilibrary.org/agriculture-and-food/private-financial-sector-investment-in-farmland-and-agricultural-infrastructure_5km7nzpjlr8v-en (accessed 27 Apr. 2017).
166 Gavras, P. (2015), 'The Geopolitics of Infrastructure Investment: Trends in the Black Sea Region', presentation given at the workshop 'Anticipating and Mitigating Major Disruptive Risks to Global Food Trade' hosted by Chatham House in London on 21 September 2015.
167 Knowler, G. (2015), 'Cargo flows across Europe face delays as refugees choke borders', *JOC*, 3 October 2015, http://www.joc.com/air-cargo/cargo-flows-across-europe-face-delays-refugees-choke-borders_20151003.html (accessed 8 Jul. 2016).
168 Griffiths, J. (2016), 'Freight transport buoyed by oil price, harmed by refugee crisis', 18 April 2016, *Financial Times,* http://www.ft.com/cms/s/2/73e4f19e-c5b0-11e5-808f-8231cd71622e.html.
169 IISS (2015), 'Armed Conflict Database Index 2015 Figures', Armed Conflict Database, http://acd.iiss.org (accessed 11 Apr. 2017).

Figure 20: Status of ongoing armed conflicts, 2017

Source: Council on Foreign Relations (2017), 'Global Conflict Tracker', updated 10 April 2017, http://www.cfr.org/global/global-conflict-tracker/p32137#! (accessed 11 Apr. 2017).

Box 5: Regional tensions and the Turkish Straits

In 2015 and 2016 tensions between Turkey and Russia rose, with their clash over the war in Syria fuelled further by military manoeuvres and power plays in the Turkish Straits (together with Turkey's shooting down of a Russian military jet in November 2015).[170] Accounts emerged of obstructive behaviour on the part of Turkish naval fleets, targeting Russian vessels transiting the Bosphorus Strait.[171] At around the same time there was a reported spike in the number of Russian warships using the strait.[172]

Most analysts consider the Turkish government highly unlikely to actually close the strait, and the subsequent rapprochement between Turkey and Russia in 2017 also renders serious obstruction less probable. Nevertheless, reports in 2015 that Turkey had deliberately delayed Russian vessels waiting to pass through the strait[173] indicate that the future blockading of this strategic chokepoint is not beyond the realms of possibility should bilateral tensions escalate again. The halting of traffic through the Bosphorus Strait in July 2016, though prompted by an attempted internal coup rather than interstate tensions and lasting only a few hours, threw into sharp relief the ease with which this key artery for food trade may be shut down when insecurity peaks.[174]

[170] Nissenbaum, D., Peker, E. and Marson, J. (2015), 'Turkey Shoots Down Russian Military Jet', *Wall Street Journal,* 24 November 2015, https://www.wsj.com/articles/turkey-shoots-down-jet-near-syria-border-1448356509 (accessed 22 May 2017).
[171] South Front (2015), 'The Russia-Turkey Standoff: Bosphorus Blockade', Foreign Policy Diary, 10 December 2015, https://southfront.org/foreign-policy-diary-russia-turkey-standoff-bosphorus-blockade (accessed 13 Jul. 2016).
[172] Pitel, L. (2016), 'Russian warships and naval assets sailing through Bosphorus strait has Turkey frightened', *Independent*, 5 March 2016, http://www.independent.co.uk/news/world/europe/russian-warships-and-naval-assets-sailing-through-bosphorus-strait-has-turkey-frightened-a6914796.html (accessed 13 Jul. 2016).
[173] Sputnik News (2015), 'Not Thinking Strait? Turkey Won't Let Russian Ships Into Bosphorus', 1 December 2015, http://sputniknews.com/world/20151201/1031038783/russia-turkey-ships-strait.html (accessed 13 Jul. 2016).
[174] Yackley, A. J. (2016), 'Turkey reopens key route for oil, grains transit after coup attempt', Reuters, 16 July 2016, http://www.reuters.com/article/us-turkey-security-shipping-idUSKCN0ZW078?il=0 (accessed 18 Jul. 2016).

The South China Sea could become a de facto chokepoint in the future if long-running maritime territorial tensions in the region were to escalate (see Box 6).[175] China's contested 'nine-dash line' claim, and its expansion of anti-access and area denial capability in the area, have raised concerns around possible restrictions on maritime activity.[176] Outright conflict has been seen as relatively unlikely, with avoiding a naval conflagration in one of the world's busiest waterways in every country's interest – not least China's, given its reliance on the South China Sea for food and energy imports. But the possibility of an escalation remains a threat, especially given the lack of clarity over recent shifts in US policy.[177]

Box 6: The South China Sea: an emerging chokepoint

A series of confrontations have occurred in the South China Sea that indicate China's intention and willingness to exert its power in the region and to challenge the principle of 'international waters'.[178] Reports that China has installed surface-to-air missiles on Woody Island in the Paracel archipelago,[179] as well as satellite imagery of expanding capacity for military aircraft built on the atolls of the Spratly Islands,[180] fuel fears that territorial tensions may rise to the point of outright conflict,[181] resulting in restrictions on maritime traffic.[182]

For commercial shipping, entering a conflict area or carrying goods destined for a country involved in conflict brings the risk of interception or harassment by military vessels.[183] Yet avoiding the South China Sea in the event of a conflict would require ships to navigate through the shallow waters of the Sunda Strait in Indonesia, or to divert course even further to the Lombok Strait and incur higher costs.[184] Ships carrying grain

[175] Kaplan, R. D. (2015), 'Why the South China Sea is so crucial', *Business Insider Australia*, 20 February 2015, http://www.businessinsider.com.au/why-the-south-china-sea-is-so-crucial-2015-2 (accessed 13 Jul. 2016); Dancel, R. (2014), 'South China Sea dispute may disrupt trade in Asia', *Straits Times*, 5 June 2014, http://www.straitstimes.com/asia/south-asia/south-china-sea-disputes-may-disrupt-trade-in-asia (accessed 13 Jul. 2016).
[176] Council on Foreign Relations (undated), 'China's Maritime Disputes', http://www.cfr.org/asia-and-pacific/chinas-maritime-disputes/p31345#!/?cid=otr-marketing_use-china_sea_InfoGuide (accessed 29 Mar. 2017); Cheng, D. (2014), 'The U.S. Needs an Integrated Approach to Counter China's Anti-Access/Area Denial Strategy', The Heritage Foundation, 9 July 2014, http://www.heritage.org/defense/report/the-us-needs-integrated-approach-counter-chinas-anti-accessarea-denial-strategy (accessed 29 Mar. 2017).
[177] Forsythe, M. (2017), 'Rex Tillerson's South China Sea Remarks Foreshadow Possible Foreign Policy Crisis', *New York Times,* 12 January 2017, https://www.nytimes.com/2017/01/12/world/asia/rex-tillerson-south-china-sea-us.html?_r=0 (accessed 21 Mar. 2017). See also UK Ministry of Defence's Development, Concepts and Doctrine Centre (2014), *Global Strategic Trends – Out to 2045*, Strategic Trends Programme, https://www.gov.uk/government/publications/global-strategic-trends-out-to-2045 (accessed 11 Apr. 2017).
[178] Bateman, S. (2015), 'The East Asian Seas: Competing national spheres of influence', in Smith, H. D., Suárez de Vivero, J. L. and Agardy, T. S. (eds), *Routledge Handbook of Ocean Resources and Management*, London: Routledge, pp. 524–538.
[179] *The Economist* (2016), 'Sunnylands and cloudy waters', 20 February 2016, http://www.economist.com/news/leaders/21693207-chinas-bullying-south-china-sea-must-not-be-allowed-pay-sunnylands-and-cloudy (accessed 8 Jul. 2016); Panda, A. (2016), 'South China Sea: China Has Deployed Anti-Ship Missiles on Woody Island', 26 March 2016, *The Diplomat*, http://thediplomat.com/2016/03/south-china-sea-china-has-deployed-anti-ship-missiles-on-woody-island (accessed 8 Jul. 2016).
[180] Center for Strategic and International Studies (undated), 'Airpower in the South China Sea', Asia Maritime Transparency Initiative, http://amti.csis.org/airstrips-scs (accessed 8 Jul. 2016).
[181] Glaser, B. S. (2015), 'Conflict in the South China Sea', Council on Foreign Relations, April 2015, http://www.cfr.org/asia-and-pacific/conflict-south-china-sea/p36377 (accessed 22 Aug. 2016).
[182] Lindsey, F. R. (1988), 'Sea Lines of Communication Control: A Marine Mission', seminar at the Marine Corps Command and Staff, Virginia, 9 May 1988, http://www.globalsecurity.org/military/library/report/1988/LFR.htm (accessed 8 Jul. 2016).
[183] Nincic, D. J. (2002), 'Sea Lane Security and U.S. Maritime Trade: Chokepoints as Scarce Resources', in Tangredi, S. J. (ed.) (2002), *Globalization and Maritime Power*, pp. 143–170, Washington, DC: Institute for National Strategic Studies, National Defense University.
[184] Brutlag, D. (2011), 'China's Reliance on Shipping Crude Oil Through the Straits of Malacca', Tufts University, http://sites.tufts.edu/gis/files/2013/02/Brutlag_Daniel.pdf (accessed 8 Jul. 2016).

along these routes would also vie for space with vessels transporting higher-value bulk commodities such as iron ore and coal, for which the Lombok and Sunda straits are key trading channels.[185]

All this would have serious implications for global food trade, and indeed for the estimated US$5 trillion in seaborne trade of all kinds that passes through the South China Sea each year.[186] Ten per cent of imports of grain into low-income food-deficit countries (LIFDCs) depend on shipments via this route, and 36 per cent of globally traded rice moves through the South China Sea each year.

3.1.2.2 Piracy

Piracy tends to occur around maritime chokepoints for obvious reasons – such waters offer a high concentration of cargo-laden vessels with land close by. Eighty-five per cent of incidents occur within the waters of just 15 countries, with Indonesia (Strait of Malacca) and Somalia (Bab al-Mandab) accounting for 50 per cent between them.[187] Piracy risk raises transport and insurance costs.[188] While piracy in the Gulf of Aden and around the Strait of Bab al-Mandab is declining following a robust international response,[189] the problem is worsening around other chokepoints: theft of cargo on ships transiting the Strait of Malacca has risen,[190] although most incidents are relatively small-scale.[191]

3.1.2.3 Terrorism

Chokepoints may provide a target for terrorists wishing to disrupt trade or damage infrastructure. Security was stepped up in the Strait of Malacca in 2010, for example, in response to intelligence that a terrorist group was planning to attack oil tankers transiting the channel.[192] Chokepoints may also provide a target for insurgencies as a means to secure access to food and energy or control distribution of high-value commodities to fund campaigns. For example, in Libya – which depends on imports for over 90 per cent of its strategic agricultural commodities[193] – attacks by Islamic State of Iraq and Syria (ISIS) on ports to gain control of oil trade led to a 30 per cent decline in wheat imports over one year as international shippers reduced port calls.[194]

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[185] Graham, E. (2006), *Japan's Sea Lane Security 1940-2004: A Matter of Life and Death?*, Oxford: Routledge.
[186] White House (2011), 'Press Briefing by NSA for Strategic Communications Ben Rhodes and Admiral Robert Willard, U.S. Pacific Command', Honolulu, Hawaii, 13 November 2011, https://obamawhitehouse.archives.gov/the-press-office/2011/11/13/press-briefing-nsa-strategic-communications-ben-rhodes-and-admiral-rober (accessed 20 Apr. 2017).
[187] Twyman-Ghoshal, A. A. and Pierce, G. (2014), 'The Changing Nature of Contemporary Maritime Piracy', *British Journal of Criminology*, 54: 652–672, doi: 10.1093/bjc/azu019 (accessed 17 Jul. 2016).
[188] Saul, J. (2013), 'West African piracy surge endangering commodities shipping', 18 June 2013, Reuters, http://www.reuters.com/article/piracy-westafrica-idUSL5N0ET31X20130618.
[189] Oceans Beyond Piracy (2015), 'The State of Maritime Piracy 2015: Assessing the Economic and Human Cost', http://oceansbeyondpiracy.org/reports/sop2015/east-africa (accessed 9 Mar. 2017).
[190] McCauley, A. (2014), 'The Most Dangerous Waters in the World', *TIME*, http://time.com/piracy-southeast-asia-malacca-strait (accessed 9 Mar. 2017).
[191] Bateman, S. (2014), *Piracy in Southeast Asia – The Current Situation*, RSIS Commentary, 7 July 2014, https://www.rsis.edu.sg/rsis-publication/idss/piracy-in-southeast-asia-the-current-situation (accessed 7 May 2017).
[192] Chatterjee, N. (2010), 'Singapore raises security alert after Malacca threat', Reuters, 5 March 2010, http://www.reuters.com/article/us-malacca-threat-idUSTRE62335120100305 (accessed 24 Feb. 2017).
[193] Chatham House (2017), resourcetrade.earth (2014 data) (accessed 28 Apr. 2017); 2014 production quantity data from FAO (2016), 'Crops', FAOSTAT, http://www.fao.org/faostat/en/#data (accessed 27 Apr. 2017).
[194] Saul, J. and Laessing, U. (2015), 'Libya food imports fall as turmoil disrupts deliveries', Reuters, 31 July 2015, http://www.reuters.com/article/libya-food-shipments-idUSL5N10A6LY20150731 (accessed 8 Jul. 2016).

3.1.2.4 Cyber insecurity

Cyber insecurity is a rapidly evolving threat to navigational and communication infrastructure.[195] It presents a growing hazard to all maritime trade, as well as to inland transport networks – like those in the US – that rely increasingly on automated and integrated communications systems.[196]

Cyber insecurity presents a growing hazard to all maritime trade, as well as to inland transport networks that rely increasingly on automated and integrated communications systems

Automated vehicles are likely to become commonplace in both commercial and military contexts, and dependence on cybersystems for safe navigation and communications will soon be the norm.[197] As a consequence of these two trends, the incidence of hijackings using denial-of-service attacks is expected to rise.[198] The heightened exposure of vessels to attack could be conducive to increased piracy in open waters, dissipating the current concentration of risk in and around major trading hubs and sea lanes. But for more sophisticated and organized criminal groups, the real targets are likely to be ports where multiple interconnected systems – navigation, cargo tracking, security – depend on satellite communications and where an attack on one system component is likely to trigger cascading impacts.[199]

The anticipated rise of denial-of-service attacks by pirates and criminal groups is particularly concerning around the Strait of Bab al-Mandab and the Gulf of Aden. Yemen and Djibouti are among the nations least well prepared for a cyberattack, both ranking 27th out of 29 (29 being the least well prepared) in a recent evaluation of risk exposure and resilience.[200]

3.1.3 Political and institutional hazards

The uninterrupted operations of transport infrastructure depend as much upon the political and regulatory context, and on the efficiency and quality of infrastructure management, as on the integrity of physical components. Bureaucratic inefficiencies, corruption and worker strikes at chokepoints all increase costs, and can restrict the movement of goods across borders or block them completely. Potentially most severe are trade restrictions imposed at chokepoints.

[195] Sommer, P. and Brown, I. (2011), *Reducing Systemic Cybersecurity Risk*, OECD/IFP Project on 'Future Global Shocks', https://www.oecd.org/gov/risk/46889922.pdf (accessed 27 Mar. 2017).
[196] UK Ministry of Defence's Development, Concepts and Doctrine Centre (DCDC) (2014), *Global Strategic Trends out to 2045*, https://www.gov.uk/government/publications/global-strategic-trends-out-to-2045 (accessed 27 Mar. 2017).
[197] Ibid.
[198] Johnson, R. (2015), *Cyber Risk*, a Joint Hull Committee paper in conjunction with Stephenson Harwood, http://www.lmalloyds.com/LMA/News/whats_hot/JHC_Cyber_Info_Paper.aspx (accessed 15 Jul. 2016).
[199] US Department of Homeland Security – Operational Analysis Division (2016), *Consequences to seaport operations from malicious cyber activity,* Critical Infrastructure Security and Resilience Note, Office of Cyber Infrastructure Analysis (OCIA), National Protection and Programs Directorate, 3 March 2016, https://info.publicintelligence.net/DHS-SeaportCyberAttacks.pdf (accessed 22 Aug. 2016).
[200] International Telecommunication Union - ABI (2015), *Global Cybersecurity Index & Cyberwellness Profiles*, Geneva: International Telecommunication Union, http://www.itu.int/dms_pub/itu-d/opb/str/D-STR-SECU-2015-PDF-E.pdf (accessed 8 Jul. 2016).

3.1.3.1 Bureaucratic inefficiencies and corruption

Sluggish border checks and inefficient trans-shipment operations delay trade through chokepoints. In Russia and Ukraine, for example, logistics and documentation procedures at the point of intake from rail and roads slow trans-shipment, constrain throughput capacity and soak up more time than the actual loading of ships.[201] The World Economic Forum ranks Russia and Ukraine 83rd and 130th respectively out of 138 economies for efficiency of customs procedures, and 103rd and 74th for freedom from excessively burdensome government regulation.[202]

Inefficiencies such as these may be compounded by corruption. The Ukrainian transport system has faced corruption issues for a number of years.[203] The United States Agency for International Development (USAID) recently pulled out of a customs reform project in Ukraine after a government drive to tackle bribe-taking at the port of Odessa lost momentum.[204] In Brazil corruption has been a considerable barrier to infrastructure improvement in recent years. At least 11 major infrastructure projects, including road and rail improvements across Brazil, have been held up by the unfolding corruption scandal around Odebrecht SA, a major Brazilian construction firm, and Braskem SA, a petrochemical company.[205]

3.1.3.2 Worker strikes

Worker strikes, while seemingly parochial disturbances, have the potential to reverberate through national and even global markets. In 2015, for example, anger in Brazil over high government diesel prices and the financial burden of taxes and tolls along export routes prompted strikes in which truckers blockaded major roads linking the soybean-growing regions to the southern ports.[206] More than 100 locations across 10 different states were subject to roadblocks, some of which remained in place for up to a week.[207] The impact on export volumes was significant: with inventories held at ports sufficient for only a few days,[208] total soybean exports in February 2015 were down 69 per cent on the same month in the previous year.[209]

[201] USDA Foreign Agricultural Service (2011), *Russian Federation: Overview of Russian Grain Port Capacity and Transportation*, GAIN Report Number RS1149, https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Overview%20of%20Russian%20Grain%20Port%20Capacity%20and%20Transportation_Moscow_Russian%20Federation_11-3-2011.pdf (accessed 28 Apr. 2017).
[202] Schwab, K. (ed.) (2016), *The Global Competitiveness Report 2016–2017*, Geneva: World Economic Forum, http://www3.weforum.org/docs/GCR2016-2017/05FullReport/TheGlobalCompetitivenessReport2016-2017_FINAL.pdf (accessed 9 May 2017).
[203] Grushevska, K. and Notteboom, T. (2016), 'From Centrality to Intermediacy in the global transport network? Ukraine's trials and tribulations as a potential transit country', *Contemporary Economic Electronic Scientific Journal*, 7(3): 69–90, https://biblio.ugent.be/publication/8162981/file/8163001 (accessed 5 Apr. 2017).
[204] Williams, M. and Polityuk, P. (2016), 'USAID ends funding for troubled Ukraine customs reform', Reuters, 30 December 2016, http://uk.reuters.com/article/uk-ukraine-crisis-corruption-USid-idUKKBN14J111?il=0 (accessed 5 Apr. 2017).
[205] Cabral, P. (2017), 'Brazil's anti-corruption probes continue, impacting projects and people', CGTN America, 21 March 2017, https://america.cgtn.com/2017/03/21/brazils-anti-corruption-probes-continue-impacting-projects-and-people (accessed 5 Apr. 2017).
[206] Reuters (2015), 'Brazil trucker strike sputters on second day', 24 April 2015, http://www.reuters.com/article/brazil-strike-truckers-idUSL1N0XL0WY20150424 (accessed 22 Jul. 2016).
[207] Freitas Jr, G. and Edgerton, A. (2015), 'Brazil Truckers Strike Slows Shipments in Battered Economy', Bloomberg, 25 February 2015, http://www.bloomberg.com/news/articles/2015-02-25/brazil-truckers-on-strike-slowing-shipments-in-battered-economy (accessed 22 Jul. 2016).
[208] Ibid.
[209] Stauffer, C. and Teixeira, M. (2015), 'Brazil truckers continue some roadblocks after crackdown', Reuters, 2 March 2015, http://www.reuters.com/article/us-brazil-strike-idUSKBN0LY1O620150302 (accessed 22 Jul. 2016).

Ninety-one per cent of grain exports and 23 per cent of exports of potash and phosphate fertilizers are from countries that currently impose export restrictions or have done so in the past decade

3.1.3.3 Trade restrictions

Chokepoints also provide a locus for trade policies and political interference to impede the passage of commodities, such as through import or export restrictions and non-tariff barriers. Such measures, when imposed by a major exporter, can have a big impact on global prices: in 2008, phosphate prices rose by 800 per cent when China, one of the world's largest producers,[210] imposed a tariff of 135 per cent on its phosphate exports.[211] The imposition of export controls by over 40 countries during the 2007–08 food price crisis amplified price rises, particularly for rice.[212] In highly concentrated fertilizer markets, export restrictions by one producer can be enough to trigger dramatic price increases (see Box 7).

Ninety-one per cent of grain exports and 23 per cent of exports of potash and phosphate fertilizers are from countries that currently impose export restrictions or have done so in the past decade.[213]

Box 7: Instability in fertilizer markets

In 2007–08, fertilizer prices tripled in the course of one year, before falling rapidly in late 2008.[214] High agricultural commodity prices, driven in part by the expansion of biofuel markets and livestock production, encouraged farmers to plant more crops and increase fertilizer usage, in turn pushing up global fertilizer prices at a time when inventories were running low.[215] The industry was slow in responding, owing in large part to the high costs of key inputs such as energy, natural gas and sulphur.[216] The imposition by China of high export tariffs further exacerbated an already tight supply–demand balance.[217]

In response to the price peak, the industry has made a concerted effort to increase capacity. But constraints and bottlenecks along fertilizer supply chains may continue to contribute to fertilizer price volatility.[218]

Several factors contribute to risks in the fertilizer market:

- **Input-intensive production brings upstream supply risk.** The reliance on primary inputs means that fertilizer traders and producers are often exposed to wider trends in commodity markets, which may lead to upstream supply disruptions. In January 2017, for example, a series of plant shutdowns in Ukraine due to high natural gas prices, and

[210] Cordell, D. and Neset, T.-S. S. (2014), 'Phosphorus vulnerability: A qualitative framework for assessing the vulnerability of national and regional food systems to the multi-dimensional stressors of phosphorus scarcity', *Global Environmental Change* 24: 108–122, http://doi.org/10.1016/j.gloenvcha.2013.11.005 (accessed 20 Apr. 2017).
[211] Hornby, L. (2008), 'China hikes tariffs to stem fertilizer exports', Reuters, 17 April 2008, http://www.reuters.com/article/us-china-fertilizer-idUSPEK27931120080417 (accessed 21 Mar. 2017).
[212] Mittal, A. (2009), *The 2008 Food Price Crisis: Rethinking Food Security Policies,* G-24 Discussion Paper Series, No. 56, June 2009, New York and Geneva: UNCTAD, https://www.g24.org/wp-content/uploads/2016/01/56.pdf (accessed 8 Mar. 2017); Headey, D. and Fan, S. (2008), 'Anatomy of a crisis: the causes and consequences of surging food prices', *Agricultural Economics*, 39(1): 375–391, doi: 10.1111/j.1574-0862.2008.00345.x (accessed 8 Mar. 2017).
[213] Chatham House (2017), resourcetrade.earth (2015 data); AMIS (2014), AMIS Policy Database, http://statistics.amis-outlook.org/policy/ (accessed 20 May 2017); OECD (2014), *Export restrictions on Industrial Raw Materials*, http://qdd.oecd.org/subject.aspx?Subject=ExportRestrictions_IndustrialRawMaterials (accessed 20 May 2017).
[214] IFDC (2008), 'World fertilizer prices drop dramatically after soaring to all-time highs', press release, 16 December 2008, https://www.eurekalert.org/pub_releases/2008-12/i-wfp121608.php (accessed 20 Apr. 2017).
[215] Huang, W.-Y. (2009), *Factors Contributing to the Recent Increase in U.S. Fertilizer Prices, 2002-08*, USDA – A Report from the Economic Research Service, https://www.ers.usda.gov/publications/pub-details/?pubid=35825 (accessed 28 Apr. 2017).
[216] Huang (2009), *Factors Contributing to the Recent Increase in U.S. Fertilizer Prices, 2002-08*; Wiggins, S., Keats, S. and Compton, J. (2010), *What caused the food price spike of 2007/08? Lessons for world cereals markets,* Overseas Development Institute Food Prices Project Report, https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/6103.pdf (accessed 27 Mar. 2017).
[217] FAO (2007), 'Food Outlook: Global Market Analysis – Fertilizers', June 2007, http://www.fao.org/docrep/010/ah864e/ah864e11.htm (accessed 27 Mar. 2017).
[218] Ott, H. (2012), *Fertilizer markets and their interplay with commodity and food prices,* JRC Scientific and Policy Reports, http://anpifert.com.pt/Estudos/JRC_Fertilizantes_e_precos_da_alimentacao.pdf (accessed 20 Apr. 2017).

a legal battle between a Russian ammonia producer and a Ukrainian pipeline operator, brought shipments of ammonia and urea from the Black Sea to a near standstill.[219]

- **Conflict and insecurity pose a disruptive risk.** The concentration of phosphate rock reserves in Morocco, Tunisia, Jordan and Syria raises concerns about the reliability of future supply should extraction, processing or export operations be interrupted by regional conflict:[220] Syria's exports of phosphate rock have decreased by 90 per cent since the civil war broke out[221] and economic sanctions were imposed by its largest buyers;[222] the Arab Spring had a considerable impact upon mining operations in Tunisia;[223] and the rekindling of tensions in Western Sahara could result in significantly tighter global phosphate supply.[224]
- **Serious supply dislocations may also occur downstream,** during the transportation of fertilizers from production plants, ports or warehouses to farmers. Developing distribution networks takes time and requires knowledge of local markets and demand, and of soil conditions. It also relies on complex logistics, from unloading at ports and inventory management to securing inland transport capacity. Only a few fertilizer companies are vertically integrated to the extent that they operate down to the farm-gate level.[225] The cost of transporting fertilizers along this final downstream stretch accounts for a substantial proportion of the final cost to the consumer.[226]
- **The inelasticity of fertilizer supply in certain markets and along supply chains constrains market responsiveness to a supply shock.** The input-intensity of fertilizer production limits capacity to respond rapidly to sudden spikes in demand; bringing new sources of supply online requires significant time and cost.[227]
- **The oligopolistic nature of phosphate and potash markets introduces the risk of anti-competitive behaviour and market distortions.**[228] Production and distribution are dominated by cartels that continue to wield a high degree of control over global supply and prices, despite indications of a possible fragmentation of these markets in recent years.[229]

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[219] Agriculture & Horticulture Development Board (2017), *Fertilizer Market Outlook,* February 2017, Issue 8, http://www.ahdb.org.uk/publications/documents/AHDBFertilizerMarketOutlookIssue8-10February2017.pdf (accessed 10 Mar. 2017).
[220] de Ridder, M., de Jong, S., Polchar, J. and Lingemann, S. (2012), *Risks and Opportunities in the Global Phosphate Rock Market*, The Hague Centre for Strategic Studies, http://www.phosphorusplatform.eu/images/download/HCSS_17_12_12_Phosphate.pdf (accessed 24 Mar. 2017).
[221] Chatham House (2017), resourcetrade.earth (comparing 2010 exports of natural calcium phosphates, ground and unground, to 2015 exports).
[222] Wellstead, J. (2012), 'Political Risks in MENA Phosphate Markets', *Business Insider*, 16 February 2012, http://www.businessinsider.com/political-risks-in-mena-phosphate-markets-2012-2?IR=T (accessed 26 Apr. 2017).
[223] Matta, S., Appleton, S. and Bleaney, M. (2015), *The Impact of the Arab Spring on the Tunisian Economy*, Centre for Research in Economic Development and International Trade, University of Nottingham, https://www.nottingham.ac.uk/credit/documents/papers/2015/15-09.pdf (accessed 24 Mar. 2017).
[224] *The Economist* (2017), 'Western Sahara edges closer to renewed conflict', 23 February 2017, http://www.economist.com/news/middle-east-and-africa/21717383-back-spotlight-fate-western-sahara-no-closer (accessed 19 Jun. 2017); and Kasprak, A. (2016), 'The Desert Rock that Feeds the World', *The Atlantic*, 29 November 2016, https://www.theatlantic.com/science/archive/2016/11/the-desert-rock-that-feeds-the-world/508853 (accessed 30 Mar. 2017).
[225] Lemarchand, L. (2017), 'Fertilizers Distribution: a business in the spotlight', IFA Production & International Trade Conference, Paris, France, 22–24 February 2017.
[226] FAO (2006), *Fertilizer use by crop*, FAO Fertilizer and Plant Nutrition Bulletin, ftp://ftp.fao.org/agl/agll/docs/fpnb17.pdf.
[227] Weber, O., Delince, J., Duan, Y., Maene, L., McDaniels, T., Mew, M., Scheidewind, U. and Steiner, G. (2014), 'Trade and Finance as Cross-Cutting Issues in the Global Phosphate and Fertilizer Market', in Scholz, R. W., Roy, A. H., Brand, F. S., Hellums, D. T. and Ulrich, A. E. (eds) (2014), *Sustainable Phosphorus Management: A Global Transdisciplinary Roadmap,* http://diyhpl.us/~nmz787/pdf/Sustainable_Phosphorus_Management.pdf, page=295 (accessed 10 Mar. 2017).
[228] Rosemarin, A. and Ekane, N. (2016), 'The governance gap surrounding phosphorus', *Nutrient Cycling in Agroecosystems*, 104(3): 265–279, http://link.springer.com/article/10.1007/s10705-015-9747-9 (accessed 28 Apr. 2017).
[229] Blas, J. and Simon, B. (2010), 'BHP faces potash cartel backlash', *Financial Times*, 26 August 2010, https://www.ft.com/content/13f300cc-b13a-11df-b899-00144feabdc0 (accessed 26 Apr. 2017); Terazano, E. (2013), 'Cartel break-up reshapes fertilizer market', *Financial Times*, 2 October 2013, https://www.ft.com/content/6b87c14c-2b80-11e3-bfe2-00144feab7de (accessed 26 Apr. 2017); MacDonald, A. (2015), 'How a Potash Cartel Collapsed', *Wall Street Journal*, 14 December 2015, https://www.wsj.com/articles/how-the-belarusian-potash-company-re-gained-its-footing-1450098821 (accessed 26 Apr. 2017).

- **Government intervention in fertilizer production or trade is a potential source of market distortion, both local and international.**[230] In India, for example, the public sector maintains a cumbersome procurement process, resulting in a 60- to 70-day lag between the decision by the government to import fertilizer and those imports reaching consumer centres.[231]

While the short-term impact on the consumer population of a price spike in fertilizers is much less acute than a direct problem with food supply, higher fertilizer prices ultimately feed through into higher retail food prices.[232] Given the increasing importance of imported fertilizer in boosting crop yields and meeting growing demand for food,[233] sustained investment in new capacity and infrastructure to overcome constraints and bottlenecks along supply chains will be required to avoid a return to the volatility seen in 2007–08.[234]

Non-tariff barriers in the form of phytosanitary regulations may also become more restrictive in the future. Climate change, increasing trade and more interconnected transport networks all risk an increase in the reach and rate of infectious disease transmission, possibly leading to a proliferation of new regulations,[235] and resulting in more stringent cargo checks and longer turnaround times at key chokepoints. For example, in recent years zoonotic infectious diseases have created difficulties for port and customs authorities in locations as diverse as the US Gulf Coast ports, the southern ports of Brazil, southern Ukraine, the Turkish Straits, the Suez Canal, the Red Sea, the Arabian Sea and the Strait of Malacca.[236]

3.2 Hazard correlation

Chokepoint disruptions do not necessarily occur in isolation. Chokepoints that are situated in relative proximity to each other may be exposed to the same localized risks, meaning that their risk of closure is likely to be highly co-dependent. Where regional conflict or extreme climate conditions threaten local chokepoints simultaneously, the risks to food security are multiplied. For example, the greatest threat to food security among the GCC countries is some kind of regional conflagration that simultaneously disrupts two or three of the critical maritime chokepoints surrounding the Arabian peninsula, drastically limiting goods access to the region (see Box 8).

[230] USAID (2012), *Building An Enabling Environment for Fertilizer Sector Growth,* http://eatproject.org/docs/USAID-EAT%20Policy%20Brief%20Fertilizer.pdf (accessed 24 Mar. 2017).
[231] Ministry of Finance, Government of India (2016), 'Reforming the Fertilizer Sector', *Economic Survey 2015-16*, http://indiabudget.nic.in/budget2016-2017/es2015-16/echapvol1-09.pdf (accessed 27 Mar. 2017).
[232] Gnutzmann, H. and Spiewanowski, P. (2016), 'Fertilizer Fuels Food Prices: Identification Through the Oil-Gas Spread', *SSRN*, http://dx.doi.org/10.2139/ssrn.2808381 (accessed 27 Mar. 2017).
[233] Ott (2012), *Fertilizer markets and their interplay with commodity and food prices*.
[234] Yara International ASA (2012), *Are nitrogen fertilizer prices still predictable?,* http://yara.com/doc/199037_YA_md_factsheet-N5_UK_12-0-BD.pdf (accessed 20 Apr. 2017).
[235] Wu, X., Lu, Y., Zhou, S., Chen, L. and Xu, B. (2016), 'Impact of climate change on human infectious diseases: Empirical evidence and human adaptation', *Environment International,* 86: 14–23, doi: 10.1016/j.envint.2015.09.007 (accessed 16 Jul. 2016); Tatem, A. J., Rogers, D. J. and Hay, S. I. (2006), 'Global Transport Networks and Infectious Disease Spread', *Advances in Parasitology*, 62: 293–343, doi: 10.1016/S0065-308X(05)62009-X (accessed 16 Jul. 2016).
[236] Jones, B. A., Grace, D., Kock, R., Alonso, S., Rushton, J., Said, M. Y., McKeever, D., Mutua, F., Young, J., McDermott, J. and Pfeiffer, D. U. (2012), 'Zoonosis emergence linked to agricultural intensification and environmental change', *PNAS*, 110(21): 8399–8404, doi: 10.1073/pnas.1208059110 (accessed 10 Aug. 2016).

Security risks to each of the Arabian chokepoints are likely to be correlated. The worst-case scenario is regional instability leading to two or three chokepoints being seriously disrupted for a sustained period

Box 8: Correlated security hazards to maritime chokepoints around the Arabian peninsula

The three key Middle Eastern maritime chokepoints of the Suez Canal, Strait of Hormuz and Strait of Bab al-Mandab face a number of security threats, some of which could coincide and have compounding effects.

The risk of an attack on the Suez Canal may be rising.[237] Terrorist activity in the Sinai Peninsula has increased in recent years,[238] and a number of terrorist attacks have been attempted[239] that have prompted the introduction of more stringent security procedures.

Iran's periodic threats to close the Strait of Hormuz have long been a concern to oil markets. While the lifting of international sanctions against Iran will almost certainly tame these threats, political and security risks remain substantial. Relations between Saudi Arabia and Iran have deteriorated as the two countries wage proxy wars across the region. The stance of the new US administration towards Iran adds to the uncertainty. Regular reports of Iranian weapons being smuggled through the Strait of Hormuz[240] further raise the stakes for controlling traffic through this key waterway.

The Strait of Bab al-Mandab remains exposed to spillover from conflict in Yemen, and to instability in nearby Somalia. However, as the recent Arab uprisings illustrate, instability in the region is contagious and conflicts are often not contained within one country. As a result, security risks to each of the individual Arabian chokepoints are likely to be correlated. The worst-case scenario is regional instability leading to two or three of the chokepoints being seriously disrupted for a sustained period.

Correlations can also occur over greater distances. For example, the imposition of export controls by a government seeking to bolster domestic food security would likely push up international prices and potentially encourage other governments to do the same. This was precisely what happened during the 2007–08 global food price crisis when over 40 governments imposed export controls at their borders as confidence collapsed and prices soared.

Teleconnection patterns within the meteorological system may also increase the risk of simultaneous weather-induced stoppages at chokepoints that are far apart. A recent taskforce on extreme weather and global food system resilience[241] recognized that teleconnections may increase the risk of simultaneous weather-related crop failures in crop-growing regions, and noted that more research was needed on the implications of climate change for this phenomenon. Food system chokepoints could be similarly at risk. For example, a scenario in which extreme floods disrupted the Brazilian road system at the same time as a tropical storm caused severe damage to US Gulf Coast ports and rendered US waterways unnavigable could have significant implications for international markets (see Box 9).

[237] Abrecht, T., Masala, C. and Tsetsos, T. (2015), 'Maritime Security in the Mediterranean, Europe's fragile underbelly', in Krause, J. and Bruns, S. (eds) (2015), *Handbook of Naval Strategy and Security*, Routledge.
[238] Council on Foreign Relations (2017), 'Global Conflict Tracker', updated 10 April 2017, http://www.cfr.org/global/global-conflict-tracker/p32137#! (accessed 11 Apr. 2017).
[239] The Maritime Executive (2015), 'Suez Canal Terrorist Attack Thwarted', 6 July 2015, http://www.maritime-executive.com/article/suez-canal-terrorist-attack-thwarted (accessed 24 Feb. 2017).
[240] Associated Press (2015), 'Iran still trying to smuggle arms to Yemen, harass passing ships: 5th Fleet', 9 November 2015, http://www.japantimes.co.jp/news/2015/11/09/world/iran-still-trying-smuggle-arms-yemen-harass-passing-ships-5th-fleet-commander/#.WLCkNn_V6ts (accessed 24 Feb. 2017).
[241] Bailey et al. (2015), *Extreme weather and resilience of the global food system*.

Box 9: The possible impact of coincident chokepoint disruptions in major crop-producing regions

Recent history can be used to illustrate the potential severity of coincident weather-related disruptions to chokepoints in multiple breadbasket regions. In 2005, Hurricane Katrina struck the port of South Louisiana, destroying 70 per cent of channel markers along the lower Mississippi River and setting adrift more than 300 barges.[242] Grain exports via the mouth of the Mississippi were halted for nearly two weeks, and traffic did not reach pre-hurricane levels again until eight weeks after Katrina's landfall.[243]

When heavy rains hit southern Brazil during a bumper harvest in 2013, exports could not be loaded on to ships at port owing to the wet conditions. Significant backlogs rapidly built up: at their peak, delays involved over 200 vessels waiting outside Brazil's main ports for an average of 39 days.[244] The effects of the disruption were not only short-term: a total of US$2.5 billion was lost to long delays and cancelled orders,[245] including a US$1.1 billion order from Sunrise Group, one of China's largest soybean importers.[246]

Were two such events to coincide, up to 50 per cent of global soybean supply could be affected.[247] And were they to coincide during the harvest and export season, either in Brazil or in the US, the potential supply shortages and price hikes could be particularly significant.

A more alarming scenario, in which chokepoint disruptions in Brazil and the US coincided with a Russian heatwave similar to that seen in the summer of 2010,[248] is also conceivable. Recent experience indicates that the ramifications would be severe. Up to 51 per cent of global soybean supply, 41 per cent of global maize supply and 18 per cent of global wheat supply could be halted or delayed.[249] (With the harvest seasons for US wheat and Russian and Brazilian spring wheat all falling in August and September,[250] the capacity of international wheat markets to respond to significant availability concerns and price hikes would be limited.) The curtailment of global wheat supply would directly affect major wheat-importing countries, many of which are among the most fragile and least food-secure;[251] the events of the Arab Spring demonstrated the politically incendiary potential of high bread prices resulting from a price shock.[252]

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[242] Envision Freight (2011), 'The Transportation of Grain', Transportation Research Board of the National Academies, http://www.envisionfreight.com/value/pdf/Grain.pdf (accessed 11 Apr. 2017).
[243] Ibid.
[244] Azoulai, Dunlop and Kuettel (2013), 'Big Bottleneck: A Weak Transportation Network Is Hurting Brazil's Once-hot Economy' (accessed 9 Mar. 2017).
[245] Thompson, J. (2013), 'Brazil Likely to Face Transport Challenges Again', United Soybean Board, 7 April 2014, http://unitedsoybean.org/article/brazil-likely-to-face-transport-challenges-again (accessed 9 Mar. 2017).
[246] Stillman, A. (2013), 'Agriculture: Bumper crops fall victim to inadequate infrastructure', *Financial Times*, 16 May 2013, http://www.ft.com/cms/s/0/c9f075ba-b7bf-11e2-9f1a-00144feabdc0.html#axzz3yRsBSmOi (accessed 24 Feb. 2017).
[247] Authors' estimate based on Chatham House Maritime Analysis Tool and Chatham House (2017), resourcetrade.earth.
[248] Kramer (2010), 'Russia, Crippled by Drought, Bans Grain Exports' (accessed 11 Apr. 2017).
[249] Authors' estimate based on Chatham House Maritime Analysis Tool and Chatham House (2017), resourcetrade.earth.
[250] AMIS (2012), *AMIS Crop Calendar*, http://www.amis-outlook.org/fileadmin/user_upload/amis/docs/resources/AMIS-online-crop-calendar_REDUCED3.pdf (accessed 11 Apr. 2017).
[251] Brinkman, H.-J. and Hendrix, C. S. (2011), *Food Insecurity and Violent Conflict: Causes, Consequences, and Addressing the Challenges*, Occasional Paper No. 24, World Food Programme, https://www.wfp.org/content/occasional-paper-24-food-insecurity-and-violent-conflict-causes-consequences-and-addressing- (accessed 11 Apr. 2017); d'Amour, C. B., Wenz, L., Kalkuhl, M., Steckel, J. C. and Creutzig, F. (2016), 'Teleconnected food supply shocks', *Environmental Research Letters* 11(035007), doi: 10.1088/1748-9326/11/3/035007 (accessed 11 Apr. 2017).
[252] USDA Economic Research Service (2015), *Middle East and North Africa Region: An Important Driver of World Agricultural Trade*, AES-88, https://www.ers.usda.gov/webdocs/publications/aes88/53335_aes88.pdf (accessed 11 Apr. 2017); Lagi, M., Bertrand, K. Z., and Bar-Yam, Y. (2011), 'The Food Crises and Political Instability in North Africa and the Middle East', SSRN, doi: 10.2139/ssrn.1910031 (accessed 11 Apr. 2017).

More broadly, a disruption of this scale would likely prompt price spikes across global food markets, with reactive trade restrictions amplifying the upward pressure on prices from a suddenly tightened supply–demand balance. The extreme price spikes of 2007–08 were primarily the result of ad hoc trade measures (fears of weather-induced supply shocks turned out to be exaggerated)[253] and were driven by a drop in global rice exports of just 9 per cent[254] – ominously, this is a far smaller supply decline than would be likely in the event of concurrent disruptions to major chokepoints.

3.3 Risk cascades

In an increasingly interconnected and complex world, dealing with high-impact, low-probability events and the 'risk cascades' that these can trigger has become a priority for governments and businesses

In an increasingly interconnected and complex world, dealing with high-impact, low-probability events and the 'risk cascades' that these can trigger has become a priority for governments and businesses. As already noted, the Arab Spring offers a cautionary tale of how a cascading chain of events in agricultural markets can interact with social and political grievances to set off a wave of uprisings, with profound and ongoing consequences for human and national security.

By their nature, strategic chokepoints could be epicentres for risk cascades. The chokepoints discussed in this report are integral not only to food trade but to a host of other economic sectors, not least energy. The Strait of Hormuz, Turkish Straits, Strait of Malacca, Suez Canal and Strait of Bab al-Mandab are all critical arteries for oil and gas.[255] Similarly, the Gulf Coast ports of the US are a major logistics hub for oil as well as grains. A major suspension to trade at one or more of these chokepoints could plausibly trigger simultaneous shocks to energy and food markets. Strategies to build resilience to risk cascades and to high-impact, low-probability events should therefore take account of chokepoints.

3.4 Chokepoint risk profiles

Each of the 14 food system chokepoints has a unique risk profile that is a function not only of the likelihood and severity of a particular hazard, but also of that chokepoint's resilience to disruption. A high degree of resilience and effective preparedness measures may limit the likelihood of closure should a hazard transpire. Equally, favourable geophysical conditions – for example, relatively wide shipping lanes – may lessen vulnerability to a hazard; high winds during a storm may pose a significant threat to vessels in the narrow channels of the Turkish Straits, but much less so to those transiting the Strait of Malacca.

Table 2 presents an approximate indication of the relative risk of closure or restricted passage for the 14 major food system chokepoints, based on the incidence of such disruptions between January 2002 and January 2017. Where three or more closures

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[253] Childs, N. and Kiawu, J. (2009), *Factors Behind the Rise in Global Rice Prices in 2008*, USDA Economic Research Service, RCS-09D-01, https://www.ers.usda.gov/webdocs/publications/rcs09d01/13518_rcs09d01_1_.pdf?v=41056 (accessed 11 Apr. 2017).
[254] Global rice exports in 2009 stood at 31.7 million tonnes, compared with 34.8 million tonnes in 2008 – Chatham House (2017), resourcetrade.earth (accessed 11 Apr. 2017).
[255] Emmerson, C. and Stevens, P. (2012), *Maritime Choke Points and the Global Energy System: Charting a Way Forward*, Briefing Paper, London: Royal Institute of International Affairs, https://www.chathamhouse.org/publications/papers/view/181615 (accessed 27 Apr. 2017).

or periods of passage restrictions have been reported during this 15-year period, the risk to the affected chokepoint is deemed 'high'; where one or two such incidents have been reported, the risk is deemed 'medium'; and where no known closures or passage restrictions have occurred during this period, the risk is 'low'. Further details of past interruptions can be found in Annex 2. This is clearly an imperfect assessment, as recent history may not reliably indicate future risk due to the changing nature of hazards. Nor does our assessment differentiate between the severity of disruptions. Nevertheless, it provides some useful insights.

Table 2: Relative disruption risk of food trade chokepoints

	Panama Canal	Dover Strait	Strait of Gibraltar	Turkish Straits	Suez Canal	Strait of Bab al-Mandab	Strait of Hormuz	Strait of Malacca	US inland waterways and rail network	US Gulf Coast ports	Brazil's inland road network	Brazil's southern ports	Black Sea rail network	Black Sea ports
Weather and climate risk														
Temperature extremes	Low	Low	Low	Low	Low	Low	Low	Low	Medium	Low	Low	Low	Low	Medium
Flood and drought	High	Low	Low	Low	Low	Low	Low	Low	High	Low	High	High	Medium	Medium
Storms	Low	Medium	Low	High	High	Low	Low	Low	High	High	Low	High	Medium	High
Haze and fog	Medium	Low	Low	Medium	Medium	Low	Low	Medium	Low	High	Low	Medium	Low	Medium
Security and conflict risk														
Conflict	Low	Low	Low	Medium	Low	Medium	Medium	Low	Low	Low	Low	Low	High	Medium
Terrorist attack	Low	Low	Low	Low	Medium	Medium	Low	Low	Low	Low	Low	Low	Low	Low
Piracy	Low	Low	Low	Low	Low	High	High	High	Low	Low	Low	Low	Low	Low
Cyberattack	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Medium	Low
Political and institutional risk														
Trade and transit controls	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Medium	Medium	High
Disrepair	Medium	Low	Low	Low	Low	Low	Low	Low	Medium	Low	Medium	High	Low	Low
Unforced delays	Low	High	Low	Low	Low	Low	Low	Low	Medium	Low	High	High	Medium	High

Authors' own analysis. Pink (high risk) = three or more known disruptions since 2002; amber (medium risk) = one or two known disruptions since 2002; aqua (low risk) = no known disruptions since 2002. For full details and sources, see Annex 2.

Based on past events, the most at-risk chokepoints are the Black Sea and Brazilian ports, and the inland transport corridors of Brazil, the Black Sea and the US.

Of the 14 chokepoints, only the Strait of Gibraltar has been free from disruption between 2002 and 2017

Of the 14 chokepoints, only the Strait of Gibraltar has been free from disruption over this period. The other 13 chokepoints have all suffered at least one disruption, although the frequency and severity of such events have varied considerably. For example, significant delays to port operations in the south of Brazil have arisen multiple times since 2002 in the wake of extreme weather events and, in 2013, lasted for over a month.[256] By contrast, delays to transit through the Panama Canal in 2015, during a period of low water levels and thick fog, averaged just 12 hours.[257]

Fifteen years of data are obviously insufficient to support conclusions about worst-case scenarios, for example at the threshold of one-in-50-year or one-in-100-year events, so it is not surprising that none of these chokepoint interruptions has had a major impact on food markets or food security. Small samples reveal little about the most damaging high-impact, low-probability events that occur in the statistical 'tails' of risk

[256] Azoulai, Dunlop and Kuettel (2013), 'Big Bottleneck: A Weak Transportation Network Is Hurting Brazil's Once-hot Economy' (accessed 9 Mar. 2017).
[257] Safety4Sea (2015), 'Panama Canal continues to experience high vessel backlog', 10 November 2015, http://www.safety4sea.com/panama-canal-continues-to-experience-high-vessel-backlog (accessed 2 Jun. 2017).

distributions. Nevertheless, what does emerge across the 14 systemic chokepoints is a picture of near-constant background disruption.

3.5 Conclusions

Chokepoint disruptions to date have been short-lived, and markets have responded in such a way as to limit reverberations through the international food system. But past experience is a poor predictor of plausible worst-case scenarios in a climate-changed world. The compounding effect of climate change on the hazards outlined above – not only relating to weather but also to insecurity and institutional risk – while not easy to quantify, increases the likelihood both of high-impact, low-probability events and of concurrent, smaller-scale disruptions to international supply chains.

Many of the hazards to which food trade chokepoints are exposed are likely to intensify

Many of the hazards to which food trade chokepoints are exposed are likely to intensify in the coming years. The extent to which these hazards will affect chokepoint operations – and thus food security – will depend greatly on the effectiveness of risk assessment and management at international, national and subnational levels. Actors at all levels will need to understand both the degree of their exposure and vulnerability to a major chokepoint dislocation, and the hazards that threaten strategic chokepoints along their supply chains.

In the next chapter, we lay out a framework for assessing chokepoint risk at national level. We also identify those countries with the highest levels of exposure and vulnerability to chokepoint disruption.

4. Chokepoint Risk and Food Insecurity

Key points

- Food trade chokepoint risk is highly context-dependent, arising from the presence of disruptive hazards and the exposure and vulnerability of countries and populations to these hazards.
- Low-income food-deficit countries (LIFDCs) – particularly in North Africa, the Horn of Africa and East Africa – are the most vulnerable to chokepoint disruption. However, a number of high-income food-deficit countries – most notably countries bordering the Persian Gulf, as well as Japan and South Korea – rank among the most exposed to chokepoint disruption.
- For countries for which exposure to chokepoint disruption is unavoidable (i.e. their geography requires that imports transit a critical chokepoint), the most effective means of mitigating risk are likely to be through contingency planning and preparedness.

Adding a 'chokepoint risk' perspective to conventional analyses of food security can reveal new insights. In this chapter we use the Chatham House Food Security Dashboard (CH-FSD) to identify countries particularly exposed to chokepoint disruptions; and to examine how chokepoint exposure may exacerbate food insecurity in countries with high levels of vulnerability. Details of the CH-FSD and its methodology are given in Annex 1.

A common conceptual framework describes risk as the product of a hazard probability distribution, pre-existing levels of exposure (the amount of economic, social or environmental assets that could be affected), and vulnerability (the propensity to be adversely affected):

Risk = Hazard (frequency; severity) x Exposure x Vulnerability

Applying this framework to national food security, we can understand chokepoint risk as the interaction of three factors: *disruptive hazards* (weather and climate, security and conflict, political and institutional – discussed in the previous chapter) at a particular chokepoint; the *degree of exposure to chokepoint disruption* (the share of national consumption accounted for by imports passing through the chokepoint or chokepoints in question); and *vulnerability* (to resultant supply interruptions or price spikes). With respect to the eight maritime chokepoints, the CH-FSD applies this framework to 205 countries using indicators of national exposure and vulnerability (see Box 10).

Box 10: Chatham House Food Security Dashboard

In order to assess national levels of exposure and vulnerability to chokepoint disruptions, we have incorporated the quantitative assessment of chokepoint reliance made possible by the Chatham House Maritime Analysis Tool (CH-MAT) with a new multi-indicator food security assessment tool: the Chatham House Food Security Dashboard (CH-FSD). The CH-FSD provides a framework with which to combine existing measures of food insecurity with a new understanding of chokepoint risk. It assesses countries' chokepoint risk in terms of their exposure (at national level) and vulnerability (at national level and at household level) to chokepoint disruption (see Table 3).

Table 3: Indicators used in Chatham House Food Security Dashboard

Dimension	Domain	Indicator
Exposure	Trade dependence	Cereal import dependency ratio (%)
	Chokepoint reliance	Aggregate maize, wheat, rice and soybean imports passing through at least one maritime chokepoint (% by weight)
		Aggregate maize, wheat, rice and soybean imports passing through a critical maritime chokepoint (% by weight)
Vulnerability	Food insecurity	Household income spent on in-home food consumption (%)
		Prevalence of undernourishment (%)
	Food availability	Aggregate stock-to-use ratio for maize, wheat, rice and soybean (%)
		Average dietary energy supply adequacy (%)
	State fragility	Fragile state? (Y/N)
		Political stability and absence of violence/terrorism. Composite indicator (approx. -2.5 to 2.5, mean=0, higher values correspond to better governance)
	Infrastructure quality	Existence of adequate crop storage facilities? (Y/N)
		Road infrastructure quality (1–7, 1=worst, 7=best)
		Rail infrastructure quality (1–7, 1=worst, 7=best)
		Port infrastructure quality (1–7, 1=worst, 7=best)
	Climate vulnerability	People killed/affected by floods, storms, droughts (per 100,000 people – worst year and annual average, 2005–14)
		Total economic damage caused by floods, storms, droughts (% of GDP – worst year and annual average, 2005–14)
	Social protection	Social protection coverage for poorest quintile (%)
	Macroeconomic vulnerability	Cash surplus/deficit (% of GDP)
		Value of food imports in total merchandise exports (%)

A full methodology can be found in Annex 1.

4.1 Exposure to maritime chokepoints

Import dependence does not necessarily imply a high degree of direct exposure to chokepoint disruption

The share of national food consumption transported through chokepoints constitutes a country's exposure to maritime chokepoint disruption. Exposure is a function of both the degree to which national food supply or prices depend on international markets, and the extent to which food imports transit particular trade routes. This section examines the exposure of different import-dependent countries to chokepoints.[258]

Broadly speaking, a high degree of dependence on food imports (including food aid) and imported inputs such as fertilizers and feed signals greater exposure to international food price shocks and to supply shocks along international supply chains.[259] That said, import dependence does not necessarily imply a high degree of *direct* exposure to chokepoint disruption if imports do not rely on key chokepoints (there may still be *indirect* chokepoint risk – the interconnectedness

[258] The CH-FSD draws on data from the CH-MAT; as such, quantitative measures of chokepoint exposure in this chapter refer to maritime chokepoints.
[259] Kornher, L. and Kalkuhl, M. (2015), *A Typology for Price-related Food and Nutrition Risks and Policy Responses*, FOODSECURE Technical Paper No. 5, http://www3.lei.wur.nl/FoodSecurePublications/TP5_Kalkuhl_15_Sept.pdf (accessed 28 Feb. 2017).

of international markets means that a supply stoppage in a major crop-growing region could, for example, affect food prices in a given country even if that country is not importing from the producer in question).

Equally, where a significant share of imported food relies on chokepoints but the share of imported food in overall supply is relatively low, or imports of the affected commodity are minimal, the impact of a chokepoint disruption will likely be muted.

But where import *and* chokepoint dependence are both high, so then is exposure to chokepoint disruption.

4.1.1 Highly exposed countries

Table 4 shows 20 of the countries most exposed to maritime chokepoint risk according to the CH-FSD. These nations are highly food import-dependent. They receive over half of their maize, wheat, rice and soybean imports via at least one maritime chokepoint.

Table 4: 20 most exposed countries to maritime chokepoint disruption

	Chokepoint exposure	
Domain	Trade dependence	Chokepoint reliance
Indicator	*Cereal import dependency ratio (%)*	*Aggregate maize, wheat, rice and soybean imports passing through at least one maritime chokepoint (%)*
Djibouti	100	79
Brunei Darussalam	98	60
Kuwait	98	95
Jordan	96	93
United Arab Emirates	95	94
Oman	93	53
Israel	93	67
Libya	92	91
Cyprus	89	73
Lebanon	88	93
Saudi Arabia	88	99
Yemen	81	54
Japan	80	71
Malaysia	76	79
South Korea	74	83
Algeria	68	69
Iraq	57	52
Tunisia	55	79
Eritrea	51	99
Angola	51	58

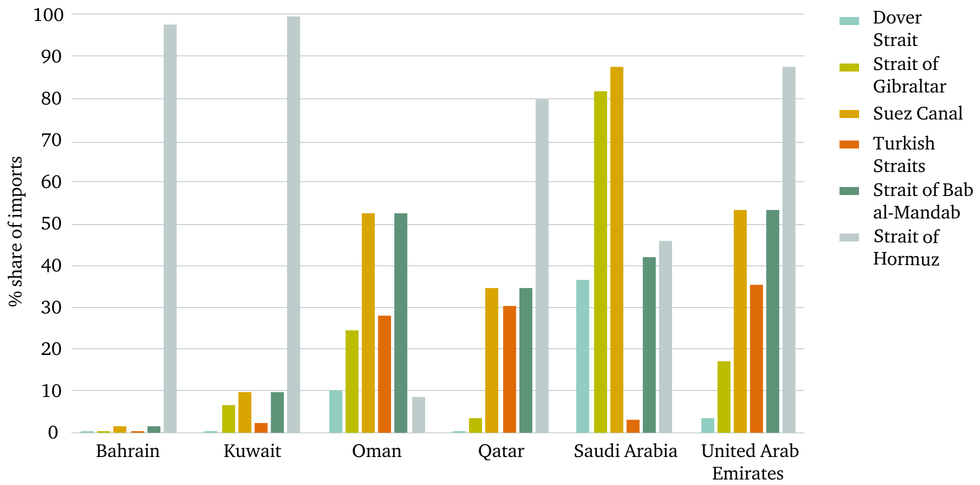
Sources: Chatham House Food Security Dashboard; FAO (2016), 'Food security indicators', http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.WTRQthiZOHp (accessed 22 Mar. 2017); Chatham House Maritime Analysis Tool; Chatham House (2017), resourcetrade.earth (2015 data).
Note: Low-income food-deficit countries indicated in italics.
Shading reflects max-min adjusted values divided into four equally sized bins: pink, amber, yellow and aqua, where pink=worst and aqua=best.

The GCC countries import high proportions of their food and rely heavily on the Arabian maritime chokepoints for delivery of those imports

The prevalence of GCC countries is immediately obvious: these countries import high proportions of their food and rely heavily on the Arabian maritime chokepoints for delivery of those imports.

Consider wheat (see Figure 21). Kuwait receives virtually all of its wheat imports via the Strait of Hormuz (as does Bahrain). For Qatar 80 per cent of imports must transit the strait. The United Arab Emirates (UAE) depends on the strait for 88 per cent of its wheat imports. This reliance has lessened since a new grain import and re-export hub at Fujairah, on the Gulf of Oman coast, started operations.[260] Nonetheless, the fact that there is no alternative maritime route into the Persian Gulf heightens risk for Kuwait, Bahrain, the UAE and Qatar.[261]

Figure 21: Share of wheat imports into GCC countries transiting selected maritime chokepoints, 2015



Sources: Chatham House Maritime Analysis Tool; Chatham House (2017), resourcetrade.earth (2015 data).

The wider MENA region also features prominently on the list of countries most exposed to maritime chokepoint disruption, with Jordan, Israel, Libya, Lebanon, Algeria, Iraq and Tunisia all making the top 20. The established link between food insecurity and conflict in the region[262] means that this extent of exposure to maritime chokepoints – in particular, to the Arabian chokepoints, where security hazards are likely to be co-dependent – is of concern.

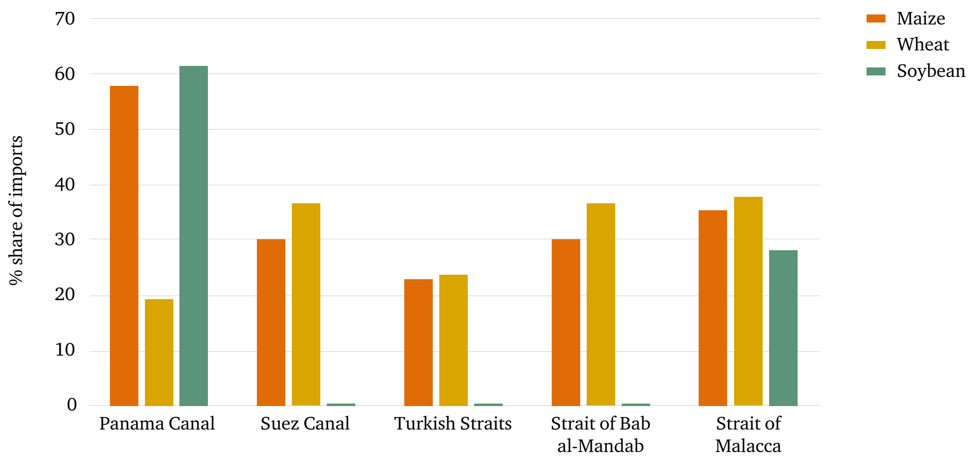
[260] USDA Foreign Agricultural Service (2016), *Grain Report*, 'United Arab Emirates – Grain and Feed Annual', Global Agricultural Information Network, Report No. UAE 03-2016, https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Grain%20and%20Feed%20Annual_Dubai_United%20Arab%20Emirates_8-11-2016.pdf (accessed 23 Mar. 2017).
[261] As the events of June 2017 illustrate, overland transport routes may not provide a reliable alternative in the case of a maritime chokepoint disruption: as part of wider political blockade, Qatar's access to cross-border flows of wheat from Saudi Arabia, the UAE and Bahrain – accounting for 17 per cent of Qatar's total wheat imports – were cut off. Sources: Chatham House Maritime Analysis Tool; Chatham House (2017), resourcetrade.earth; Taylor, A. (2017), 'Qatar could face a food crisis in spat with Arab neighbours', *Washington Post*, 5 June 2017, https://www.washingtonpost.com/news/worldviews/wp/2017/06/05/qatar-could-face-a-food-crisis-in-spat-with-arab-neighbors/?utm_term=.5b11971a8814 (accessed 19 Jun. 2017).
[262] Maystadt, J.-F., Trinh Tan, J.-F. and Breisinger, C. (2012), *Does Food Security Matter for Transition in Arab Countries?*, International Food Policy Research Institute, IFPRI Discussion Paper 01196, July 2012, http://dspace.africaportal.org/jspui/bitstream/123456789/32993/1/ifpridp01196.pdf?1 (accessed 26 Apr. 2017).

Most troubling among the list of highly exposed markets is the presence of a handful of low-income countries: Djibouti, Eritrea and Yemen

The number of wealthy countries on the list is also notable. Three of the world's biggest 20 economies by GDP – Japan, South Korea and Saudi Arabia[263] – feature on it. So do the high-income countries of Brunei, Oman, Cyprus and – as mentioned – Israel, Kuwait and the UAE. Conventional economic analyses of national food security tend to assume that rich countries are food-secure irrespective of their import dependency, because wealth makes them resilient to international price rises. The implicit assumption is that markets will continue to function in the worst-case scenario; however, it is clear that high degrees of chokepoint exposure mean that some wealthy countries cannot necessarily count on uninterrupted access to markets and need to consider the risk of import dislocations arising from chokepoint disruption.

South Korea, for example, is dependent on imports for three-quarters of its cereal supply. Four-fifths of this imported supply transits at least one maritime chokepoint. In all, around 60 per cent of the country's maize and soybean imports pass through the Panama Canal; and roughly a third of South Korea's maize imports and just over a third of its wheat imports must pass through no fewer than three chokepoints en route from Eastern Europe, as they transit the Suez Canal, the Strait of Bab al-Mandab and the Strait of Malacca in succession (see Figure 22).

Figure 22: Share of maize, wheat and soybean imports into South Korea transiting selected maritime chokepoints, 2015



Sources: Chatham House Maritime Analysis Tool; Chatham House (2017), resourcetrade.earth (2015 data).

Most troubling among the list of highly exposed markets is the presence of a handful of low-income food-deficit countries: Djibouti, Eritrea and Yemen. As the CH-FSD reveals, these countries are highly vulnerable to international food market instability. For example, in Yemen over a quarter of the population is undernourished, nearly half of all household income is spent on food, stock levels of staple crops are very low, and social protection measures for the country's poorest people are far short of adequate. Yemen is an extremely fragile country, destabilized by ongoing war that has had a ruinous impact on infrastructure. At the time of writing, the country was on the brink of famine. With a dependence on imports for four-fifths of its cereal supply, and with half

[263] World Bank (2017), 'GDP ranking', 2015 data, http://data.worldbank.org/data-catalog/GDP-ranking-table (accessed 22 Mar. 2017).

of these shipments passing through chokepoints, Yemeni food consumption is at high risk from supply interruptions, as has happened in recent months due to the Saudi-led coalition's naval blockade of the country.

4.1.2 China

As discussed in Chapter 2, Chinese imports of strategic commodities, particularly soybean, have been growing, and so has its dependency on the Strait of Malacca and Panama Canal. Despite this, China's maritime chokepoint exposure remains relatively low: its policy of self-sufficiency in cereals means that it has only small trade deficits in wheat and maize, although rising demand on the one hand and soil depletion, water scarcity and an ageing rural workforce on the other mean that these deficits may gradually widen.[264]

China has maintained self-sufficiency in cereals by increasing its imports of foodstuffs that compete for land – in particular oilseeds. In 2015, Chinese imports accounted for nearly 40 per cent of the global trade in soybean.[265] This import dependence is expected to rise: in 2000, the country's net annual soybean imports were 10 million tonnes; by 2025, this figure is projected to reach 106 million tonnes.[266] Just under 90 per cent of China's grain and fertilizer imports can be expected to pass through the Strait of Malacca or the Panama Canal. Yet with improving levels of food security (only 9 per cent of the population is undernourished, and less than a fifth of household income is spent on food), and with the majority of agricultural imports being fed to livestock rather than humans, China is relatively resilient to a chokepoint hazard directly affecting its population's caloric needs. Nevertheless, as will be explored in the next chapter, China is acutely aware of this (limited) exposure and is actively seeking to reduce it.

4.2 Highly vulnerable countries

As the discussion of Yemen illustrates, exposure to chokepoint disruption poses a more serious threat to food security in countries in which vulnerability is high. It is therefore important to pay particular attention to the chokepoint risks of the most vulnerable countries.

Table 5 shows vulnerability indicators from the CH-FSD for the most vulnerable countries according to traditional measures of food insecurity. More than a quarter of the population in these countries is chronically undernourished, and on average households spend more than a quarter of their income on food. Selected other food-insecure countries with significant chokepoint exposure are also shown. For vulnerable countries, even a relatively small chokepoint shock may result in disproportionately large impacts.

[264] Dalin, C., Qiu, H., Hanasaki, N., Mauzerall, D. and Rodriguez-Iturbe, I. (2015), 'Balancing water resource conservation and food security in China', *PNAS*, 112(15): 4588-4593, doi: 10.1073/pnas.1504345112 (accessed 18 Jun. 2017); Guo, G., Wen, Q. and Zhu, J. (2015), 'The Impact of Aging Agricultural Labor Population on Farmland Output: From the Perspective of Farmer Preferences', *Mathematical Problems in Engineering*, Article ID 730618, doi: 10.1155/2015/730618 (accessed 18 Jun. 2017).
[265] Chatham House (2017), resourcetrade.earth.
[266] OECD-FAO (undated), OECD-FAO Agricultural Outlook, 'Compare countries', http://www2.compareyourcountry.org/agricultural-outlook?cr=wld&lg=en&page=1 (accessed 26 Apr. 2017).

Table 5: Selected indicators of chokepoint vulnerability from the CH-FSD

	Chokepoint exposure		**Chokepoint vulnerability**						
Domain	Trade dependence	Chokepoint reliance	Food insecurity		Food availability		State fragility		Social protection
Indicator	*Cereal import dependency ratio (%)*	*Aggregate maize, wheat, rice and soybean imports passing through at least one maritime chokepoint (%)*	*Household income spent on in-home food consumption (%)*	*Prevalence of undernourish-ment (%)*	*Aggregate stock-to-use ratio for maize, soybean, rice, wheat (%)*	*Average dietary energy supply adequacy (%)**	*Fragile state (Y/N)*	*Political stability and absence of violence/ terrorism***	*Social protection coverage for poorest quintile (%)*
Haiti	54	15	58	53	6	87	Y	-0.61	1
Zambia	-8	34	58	48	33	92	N	0.21	1
Central African Republic	21	23	57	48	.	87	Y	-2.67	.
Chad	10	32	48	34	1	103	Y	-1.53	.
Zimbabwe	49	16	56	33	6	98	Y	-0.65	13
Tajikistan	44	0	44	33	26	97	N	-0.68	14
Madagascar	9	27	44	33	0	97	Y	-0.54	2
Tanzania	13	66	66	32	19	105	N	-0.54	13
Ethiopia	11	86	37	32	6	99	Y	-1.24	16
Liberia	61	50	27	32	6	109	Y	-0.63	63
Rwanda	24	51	48	32	6	105	Y	-0.10	1
Congo, Rep.	93	41	37	31	.	97	Y	-0.29	3
Swaziland	73	0	46	27	.	98	N	-0.52	77
Yemen	81	54	45	26	5	102	Y	-2.53	19
Uganda	9	74	33	26	7	108	Y	-0.93	75
Mozambique	27	56	52	25	4	110	N	-0.35	8
Select other food-insecure countries with chokepoint exposure									
Sudan	.	98	52	.	7	.	Y	-2.36	.
Burundi	21	50	44	.	.	.	Y	-0.89	.
Kenya	36	60	34	21	10	102	Y	-1.27	36
Djibouti	100	79	30	16	.	115	N	-0.72	33

Sources: Chatham House Food Security Dashboard; Chatham House (2017), resourcetrade.earth (2015 data); FAO (2016), 'Food security indicators'; World Bank (2011), 'International Comparison Program', http://siteresources.worldbank.org/ICPEXT/Resources/ICP_2011.html (accessed 3 Jun. 2017); USDA Foreign Agricultural Service (2017), 'Production, Supply and Distribution', https://apps.fas.usda.gov/psdonline/app/index.html#/app/advQuery (accessed 3 Jun. 2017); OECD (2015), *States of Fragility 2015: Meeting Post-2015 Ambitions*, Paris: OECD Publishing, doi: 10.1787/9789264227699-en (accessed 5 Jun. 2017); World Bank (2015), 'Worldwide Governance Indicators', http://info.worldbank.org/governance/wgi/index.aspx#home (accessed 3 Jun. 2017); World Bank (undated), 'ASPIRE Indicators at a glance', http://datatopics.worldbank.org/aspire/indicator_glance (accessed 3 Jun. 2017).

* Caloric supply as percentage of average requirement. Values below or close to 100 suggest inadequate supply for some members of the population and vulnerability to imperfect food distribution.

** Composite indicator (approx. -2.5 to 2.5, mean=0), higher values=better governance.

Shading reflects max-min adjusted values divided into four equally sized bins: pink, amber, yellow and aqua, where pink=worst and aqua=best.

What is immediately obvious, and unsurprising, is the prevalence of sub-Saharan African countries in the list of highly vulnerable countries. Although some have relatively modest exposure to chokepoints, many countries – notably Burundi, Djibouti, Ethiopia, Kenya, Liberia, Mozambique, Rwanda, Sudan, Tanzania and Uganda – rely on maritime chokepoints for 50 per cent or more of their grain imports.

4.2.1 Vulnerability in East Africa

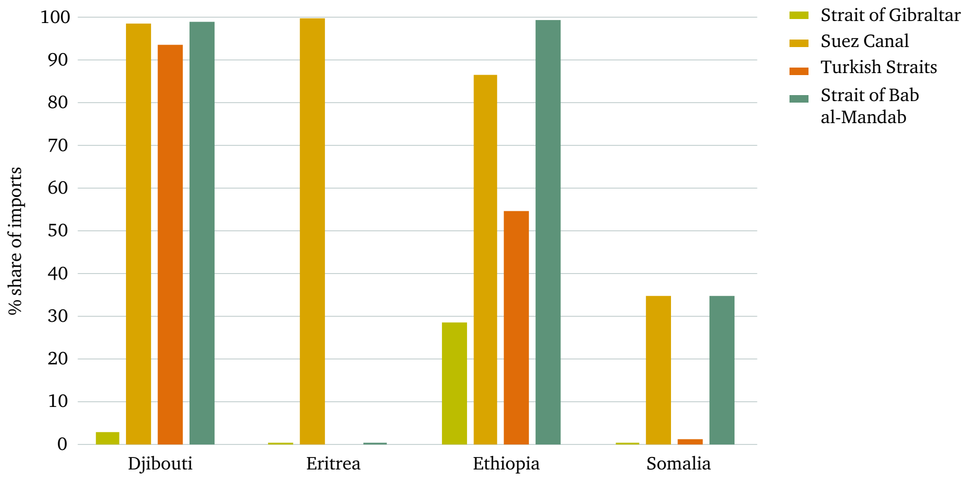
One region of sub-Saharan Africa with high levels of vulnerability and material exposure is East Africa. East African wheat imports are particularly exposed: between 69 per cent (in the case of Tanzania) and 92 per cent (in the case of Uganda) transit the Suez Canal and the Strait of Bab al-Mandab. Large shares of these imports are sourced from Russia. In 2013, 22 per cent of wheat imports into Rwanda, 21 per cent of wheat imports into Uganda, 20 per cent of wheat imports into Tanzania and 30 per cent of wheat imports into Kenya originated in Russia (shares equivalent to 24 per cent, 16 per cent, 20 per cent and 17 per cent of domestic wheat consumption respectively).[267] And dependence on Russia is increasing: by 2015, Russia's share of imports into Rwanda, Uganda and Tanzania had risen to 59 per cent, 42 per cent and 40 per cent respectively. Populations in East Africa are thus exposed to the risk not only of a major disruption to the Arabian maritime chokepoints, but of delays or supply cancellations along Russian railways, at Russian ports, or through the Turkish Straits.

Food aid delivered by the World Food Programme (WFP) is a critical source of supply. But the WFP relies on shipping for over half of its food aid deliveries

Of particular concern is the degree of chokepoint exposure of countries in the Horn of Africa, already one of the most food-insecure regions in the world. Countries in this region typically have high structural vulnerability, with high levels of malnutrition, high levels of household spending on food, and very high government spending on food imports as a proportion of foreign exchange reserves. The region is acutely vulnerable to climate impacts and has high levels of state fragility. At the time of writing a major food crisis had engulfed the region, with famine declared in South Sudan and possible in Somalia.[268] Food aid delivered by the World Food Programme (WFP) is a critical source of supply in such circumstances. But the WFP relies on shipping for over half of its food aid deliveries.[269] The port at Djibouti is particularly important, handling 86 per cent of deliveries destined for Ethiopia and hosting the WFP's regional storage and logistical hub.[270] To arrive at Djibouti port, 99 per cent, 98 per cent, 86 per cent and 35 per cent of international wheat shipments into Eritrea, Djibouti, Ethiopia and Somalia respectively must pass through the Suez Canal (see Figure 23). Were this supply artery to be closed off, prospects for distributing essential food supplies to affected communities would be severely limited.

[267] Authors' calculation based on wheat imports from Russia in 2013 (Chatham House (2017), resourcetrade.earth) and wheat supply data in 2013 (FAOSTAT, 'Food Supply – Crops Primary Equivalent', http://www.fao.org/faostat/en/#data/CC).
[268] FEWS NET (2017), 'Famine (IPC Phase 5) likely ongoing in parts of South Sudan; risk of famine (IPC Phase 5) continues in Somalia', February 2017, http://www.fews.net/east-africa (accessed 22 Mar. 2017).
[269] World Food Programme (undated), 'Shipping', https://www.wfp.org/logistics/shipping (accessed 22 Mar. 2017).
[270] World Food Programme (2010), 'WFP Logistics: We Do More Than Just Deliver', 8 October 2010, https://www.wfp.org/logistics/blog/wfp-logistics-we-do-more-just-deliver (accessed 22 Mar. 2017).

Figure 23: Share of wheat imports into the Horn of Africa transiting selected maritime chokepoints, 2015



Sources: Chatham House Maritime Analysis Tool; Chatham House (2017), resourcetrade.earth (2015 data).

The absence at national or regional level of robust and secure transport networks to connect food-insecure communities with available stocks, local markets or food aid distribution centres also heightens these countries' vulnerability to chokepoint disruption.

4.2.2 Low-income food-deficit countries (LIFDCs)

Vulnerability is high among the low-income food-deficit countries

Vulnerability is also high among the low-income food-deficit countries (LIFDCs, see Table 6).[271] Of the 54 countries classified by the UN Food and Agriculture Organization (FAO) as LIFDCs, 35 are also designated as fragile states by the OECD; all bar five are in the bottom half of countries in terms of their scores for the World Bank's measure of political stability and absence of violence or terrorism.[272] Undernourishment is widespread in many (though by no means all) of these countries, and households typically spend a high proportion of their income on food. Food availability, as defined by caloric supply and stock-to-use ratios for staple foods, is insufficient. Social protection coverage for the poorest segments of the population is also typically inadequate in LIFDCs (Lesotho, Mongolia and Uganda being notable exceptions). Transport infrastructure is a widespread weakness, although more than half of those countries for which data are available do have adequate crop storage facilities. Thus, access to and distribution of sufficient food stocks are key challenges for the vast majority of these countries.

[271] Defined by the Food and Agriculture Organization of the United Nations (FAO), based on gross national income below the World Bank's eligibility threshold for International Development Association (IDA) assistance, negative net food trade position, and whether a country meeting these criteria requests exclusion from the classification. FAO (undated), 'Low-income Food-Deficit Countries (LIFDC) – List for 2015', http://www.fao.org/countryprofiles/lifdc/en (accessed 27 Apr. 2017).
[272] Kaufmann, D. and Kraay, A. (2015), 'Worldwide Governance Indicators', World Bank, http://info.worldbank.org/governance/wgi/index.aspx#home (accessed 23 May 2017).

Table 6: Low-income food-deficit countries – selected indicators of chokepoint vulnerability from the CH-FSD

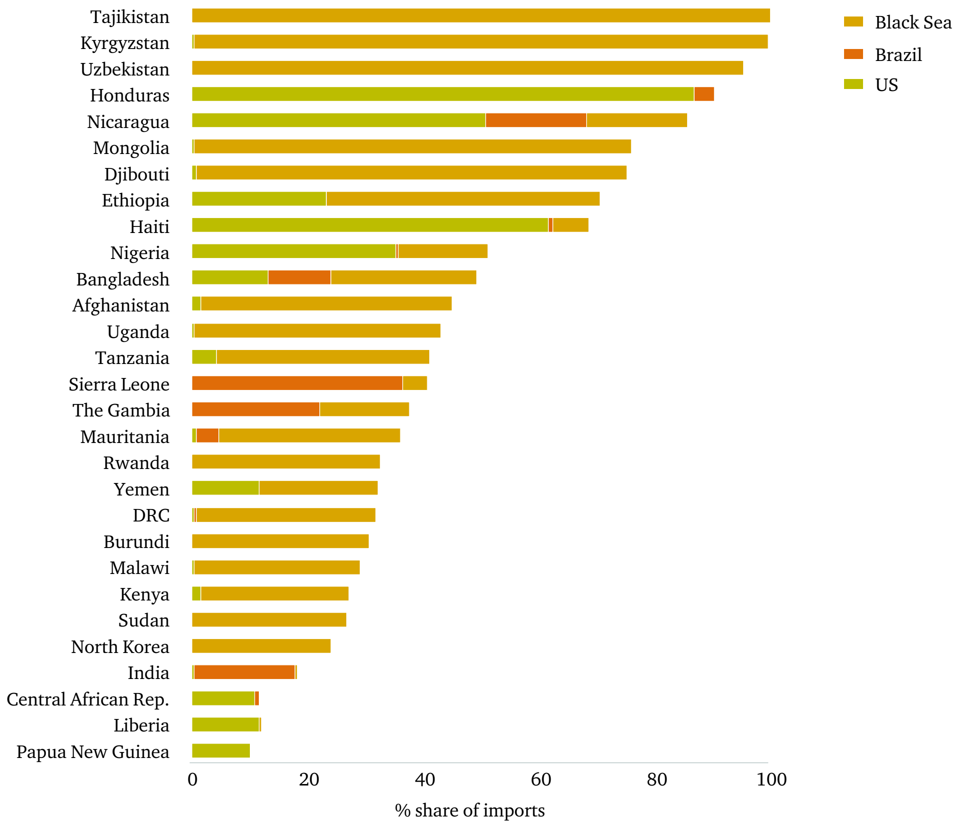
	Chokepoint exposure		Chokepoint vulnerability										
Domain	Trade dependence	Chokepoint reliance	Food insecurity		Food availability		State fragility		Social protection	Infrastructure quality			
Indicator	*Cereal import dependency ratio (%)*	*Aggregate maize, wheat, rice and soybean imports passing through at least one maritime chokepoint (%)*	*Household income spent on in-home food consumption (%)*	*Prevalence of undernourishment (%)*	*Aggregate stock-to-use ratio for maize, soybean, rice, wheat (%)*	*Average dietary energy supply adequacy (%)**	*Fragile state (Y/N)*	*Political stability and absence of violence/ terrorism.***	*Social protection coverage for poorest quintile (%)*	*Existence of adequate crop storage facilities (Y/N)*	*Road infrastructure (1–7, 7=best)*	*Rail infrastructure (1–7, 7=best)*	*Port infrastructure (1–7, 7=best)*
Haiti	54	15	58	53	6	87	Y	-0.61	1	Y	2.3	.	2.6
Central African Republic	21	23	57	48	.	87	Y	-2.67	.	.	.	.	.
North Korea	12	25	.	42	0	88	Y	-1.09	.	.	.	.	.
Chad	10	32	48	34	1	103	Y	-1.53	.	N	3.0	.	1.4
Zimbabwe	49	16	56	33	6	98	Y	-0.65	13	.	3.3	2.2	3.2
Tajikistan	44	0	44	33	26	97	N	-0.68	14	N	3.6	3.4	2.1
Madagascar	9	27	44	33	0	97	Y	-0.54	2	Y	2.2	1.7	3.2
Tanzania	13	66	66	32	19	105	N	-0.54	13	Y	3.3	2.1	3.4
Ethiopia	11	86	37	32	6	99	Y	-1.24	16	Y	3.7	2.7	3.2
Liberia	61	50	27	32	6	109	Y	-0.63	63	.	2.7	2.7	3.6
Rwanda	24	51	48	32	6	105	Y	-0.10	1	N	4.9	.	3.3
Afghanistan	24	2	.	27	5	99	Y	-2.46	12	.	.	.	.
Yemen	81	54	45	26	5	102	Y	-2.53	19	Y	.	.	.
Uganda	9	74	33	26	7	108	Y	-0.93	75	N	3.4	1.5	2.5
Mozambique	27	56	52	25	4	110	N	-0.35	8	N	2.3	2.3	3.6
Sierra Leone	20	35	40	22	.	111	Y	-0.22	35	N	2.7	.	2.8
Kenya	36	60	34	21	10	102	Y	-1.27	36	Y	4.2	2.6	4.2
Burkina Faso	10	28	51	21	7	123	N	-0.79	36	N	.	.	.
Guinea-Bissau	31	42	51	21	3	110	Y	-0.74	.	.	.	.	.
Malawi	2	44	49	21	7	111	Y	0.12	20	Y	3.2	1.8	2.2
Mongolia	35	75	29	21	.	109	N	0.87	90	.	2.8	2.5	1.4
Nicaragua	32	25	26	17	13	117	N	-0.05	55	N	3.6	.	2.8
Guinea	14	54	58	16	10	118	Y	-0.93	.	N	1.9	1.4	2.9
Bangladesh	11	62	51	16	8	108	Y	-0.88	28	Y	2.9	2.5	3.6
Djibouti	100	79	30	16	.	115	N	-0.72	33	.	.	.	.
India	-3	4	28	15	12	108	N	-0.96	27	Y	4.1	4.1	4.2
Côte d'Ivoire	52	35	43	13	15	131	Y	-1.01	3	N	4.8	2.7	5.2
Honduras	57	4	30	12	14	122	N	-0.51	65	N	3.9	.	4.6

	Chokepoint exposure		Chokepoint vulnerability										
Domain	Trade dependence	Chokepoint reliance	Food insecurity		Food availability		State fragility		Social protection	Infrastructure quality			
Indicator	*Cereal import dependency ratio (%)*	*Aggregate maize, wheat, rice and soybean imports passing through at least one maritime chokepoint (%)*	*Household income spent on in-home food consumption (%)*	*Prevalence of undernourishment (%)*	*Aggregate stock-to-use ratio for maize, soybean, rice, wheat (%)*	*Average dietary energy supply adequacy (%)**	*Fragile state (Y/N)*	*Political stability and absence of violence/ terrorism***	*Social protection coverage for poorest quintile (%)*	*Existence of adequate crop storage facilities (Y/N)*	*Road infrastructure (1–7, 7=best)*	*Rail infrastructure (1–7, 7=best)*	*Port infrastructure (1–7, 7=best)*
Togo	14	39	43	11	8	122	Y	-0.16	.	Y	.	.	.
Solomon Islands	97	0	.	11	.	114	Y	0.49	2	.	.	.	.
Lesotho	78	0	26	11	.	116	N	-0.27	93	.	3.6	.	2.7
Senegal	47	36	49	10	14	111	N	-0.13	8	Y	3.7	2.3	4.1
Cameroon	26	35	46	10	8	118	Y	-0.94	1	N	2.8	2.7	3.3
Niger	7	36	42	10	.	125	Y	-1.27	3	Y	.	.	.
Nepal	4	1	56	8	2	121	Y	-0.70	53	Y	2.8	.	1.6
Benin	22	50	48	8	3	127	N	0.05	.	N	2.7	1.5	3.4
Nigeria	22	49	38	7	4	123	Y	-2.11	3	Y	2.7	1.5	3.0
São Tomé and Principe	.	60	55	7	.	119	N	0.15	.	.	.	.	.
Kyrgyzstan	23	0	38	6	9	122	N	-0.78	17	.	2.6	2.4	1.5
Mauritania	74	48	60	6	18	132	Y	-0.58	46	.	2.3	2.1	2.7
The Gambia	44	35	43	5	9	132	N	-0.10	2	.	4.1	.	4.1
Uzbekistan	18	3	.	0	25	122	N	-0.23	.	Y	.	.	.
Mali	5	9	47	0	17	137	Y	-1.74	.	Y	3.2	2.1	2.5
Ghana	26	49	37	0	9	150	N	-0.13	6	Y	3.2	2.2	3.5
Bhutan	.	0	29	.	.	.	N	1.00	4	.	4.0	.	1.8
Burundi	21	50	44	.	.	.	Y	-0.89	.	Y	3.2	.	2.8
Comoros	71	17	51	.	.	.	Y	-0.19	.	.	.	.	.
DRC	34	39	55	.	4	.	Y	-2.27	5	N	.	.	.
Eritrea	51	99	.	.	.	.	Y	-0.76	.	.	.	.	.
Papua New Guinea	96	8	.	.	9	.	N	-0.33	2	.	.	.	.
Somalia	70	20	.	.	.	.	Y	-2.49	.	.	.	.	.
South Sudan	.	0	.	.	.	.	Y	-2.54	.	.	.	.	.
Sudan	.	98	52	.	7	.	Y	-2.36	.	N	.	.	.
Syria	43	87	.	.	30	.	Y	-2.76	.	Y	.	.	.

Sources: Chatham House Food Security Dashboard; Chatham House (2017), resourcetrade.earth (2015 data); FAO (2016), 'Food security indicators'; World Bank (2011), 'International Comparison Program'; USDA Foreign Agricultural Service (2017), 'Production, Supply and Distribution'; OECD (2015), *States of Fragility*; World Bank (2015), 'Worldwide Governance Indicators'; World Bank (undated), 'ASPIRE Indicators at a glance'; Economist Intelligence Unit (2016), 'Global Food Security Index', http://foodsecurityindex.eiu.com (accessed 3 Jun. 2017); Schwab, K. (ed.) (2015), *The Global Competitiveness Report 2015–2016*, Geneva: World Economic Forum, http://www3.weforum.org/docs/gcr/2015-2016/Global_Competitiveness_Report_2015-2016.pdf (accessed 9 May 2017).
* Caloric supply as percentage of average requirement. Values below or close to 100 suggest inadequate supply for some members of the population and vulnerability to imperfect food distribution.
** Composite indicator (approx. -2.5 to 2.5, mean=0), higher values=better governance.
Shading reflects max-min adjusted values divided into four equally sized bins: pink, amber, yellow and aqua, where pink=worst and aqua=best.

Even if their exposure to maritime chokepoints is low, LIFDCs are still exposed to inland and coastal chokepoints in major crop-producing regions. This exposure can be direct, in that they import from one or more producer regions; or indirect, in that a major disruption at a chokepoint in one of these regions could affect international prices, and therefore import costs, whether or not that region is a source of imports. In fact, many LIFDCs are directly reliant on breadbasket regions, particularly the Black Sea, for their imports (see Figure 24).

Figure 24: LIFDC dependence* on Brazil, the Black Sea and the US for imports of maize, wheat, rice and soybean, 2015



*Showing only those LIFDCs that depend on the Black Sea, Brazil or the US for more than 10 per cent of grain imports.
Source: Chatham House (2017), resourcetrade.earth (2015 data).

4.3 Conclusions

An assessment of national exposure to chokepoint disruption brings a new dimension to comparative degrees of food security: Japan and South Korea, two of the richest countries in the world, are among the most exposed to the interruption of food imports – on which they are highly dependent – at critical chokepoints; and China, though boasting only marginal trade deficits in wheat and maize, relies heavily on the Strait of Malacca and Panama Canal for those commodities that it imports. Above all, the inclusion of chokepoint reliance within a cross-country assessment serves to underline the vulnerability of the lowest-income food-insecure nations, particularly those in North Africa, the Middle East and sub-Saharan Africa.

In the following chapter, we consider steps that national governments and international organizations have taken to manage food supply risk, and the degree to which chokepoint risk has been addressed, before outlining priority areas for action at international and national level.

5. Managing Chokepoint Risk

Key points

- Governments have responded in multiple ways to food market instability, but very few have addressed chokepoint risk.
- Many governments of food-importing countries have invested in production and export capacity overseas. However, few have matched this with a diversification of import routes. China is a notable exception.
- While the smooth operation of global trade chokepoints is in the interests of all, investment in critical infrastructure is lacking both in crop-producing regions and food-importing regions.
- A governance gap exists around chokepoint management, arising from the mismatch between national ownership and international strategic interests.
- Cooperative approaches to risk mitigation and preparedness – through both investment and governance – are needed to balance national priorities with systemic resilience.

As yet, only a handful of states have explicitly responded to chokepoint risk. Managing food price volatility has received significant policy attention at national and international level since the 2007–08 and 2010–11 food price crises, but policy approaches have tended to overlook – and, in some cases, exacerbate – exposure and vulnerability to chokepoint disruption.

Policy has tended to overlook exposure and vulnerability to chokepoint disruption

Below, we explore the ways in which governments have responded to food market instability. We then outline the governance gap that persists both around the management of chokepoint risk as it pertains to national infrastructure and international maritime straits, and around preparedness for future systemic disruptions.

5.1 Government responses

Governments responded in many different ways to the most recent periods of food market instability, with some interventions designed to reduce price volatility and mitigate its impacts, and others designed to increase security of supply. Below we briefly summarize some notable responses, many from Gulf countries or China, and consider the extent to which these successfully address chokepoint risks.

5.1.1 Collective action to tackle price volatility

At the recommendation of a taskforce of 10 international organizations, in 2011 the G20 established the Agricultural Market Information System (AMIS) to increase market transparency and monitor leading indicators of market volatility. Based on the Joint Organisations Data Initiative (JODI) to improve transparency in oil markets, AMIS has made progress in improving reporting on agricultural stock levels and market fundamentals. It also provides market monitoring and a mechanism (the Rapid Response Forum) through which governments can collectively discuss and agree coordinated responses to market volatility. In addition to monitoring market fundamentals, AMIS tracks a wide range of volatility indicators, including stock-to-use ratios, energy prices, freight rates, input costs, dollar indices, biofuel policies and trade policies. It does not, however, consider chokepoints.

5.1.2 Boosting domestic availability

Concerns about food security, both in the run-up to and following the 2007–08 crisis, led to a proliferation of government support for agricultural production and other measures to increase domestic food supply. In response to low domestic stock levels and rising global prices in 2006–07, for example, India launched a 2007–08 National Food Security Mission aimed at boosting domestic grain production within five years; this scheme significantly increased the guaranteed minimum price paid by the government to farmers for wheat and rice.[273] Similarly, to promote domestic grain production, China raised direct payments to farmers and increased government subsidies for inputs such as fertilizers, seeds and fuel.[274]

Strategic stock-building has been a second important means of reducing reliance on imports.[275] These strategies can be expensive, particularly in countries with little comparative advantage in agriculture or where weak governance means stocks are likely to be mismanaged. Nevertheless, they can potentially reduce vulnerability to unexpected import curtailments, whether due to chokepoint disruption or otherwise.

In deciding where to locate strategic grain silos or bunkers, it may be important for governments to consider chokepoints. Clearly, if the stocks are to be of use in a crisis, access to vulnerable populations is important. And if the stocks are to be maintained, they must be supported by reliable supply chains. This has evidently been a consideration for Gulf countries in recent years; governments in the region have sought to reduce silo supply chains' reliance on the Strait of Hormuz. Saudi Arabia has expanded its storage capacity on the Red Sea coast,[276] while the UAE has developed a new grain silo complex in Fujairah, south of the Strait of Hormuz, creating a supply hub that does not depend on imports transiting the strait.[277]

[273] Saini, S. and Gulati, A. (2016), 'India's Food Security Policies in the Wake of Global Food Price Volatility', in Kalhul, M., von Braun, J. and Torero, M. (2016), *Food Price Volatility and Its Implications for Food Security and Policy,* Springer Nature eBook, doi: 10.1007/978-3-319-28201-5, http://link.springer.com/chapter/10.1007/978-3-319-28201-5_14 (accessed 24 May 2017).
[274] Yu, W. and Jensen, H.G. (2011), *Trade policy responses to food price rises and implications for existing domestic support measures: the case of China in 2008*, paper prepared for presentation at the EAAE 2011 Congress, 'Change and Uncertainty: Challenges for Agriculture, Food and Natural Resources', 30 August to 2 September 2011, Zurich, Switzerland, http://ageconsearch.umn.edu/bitstream/115970/2/Yu_Wusheng_605.pdf (accessed 2 Jun. 2017).
[275] Maetz, M., Aguirre, M., Kim, S., Matinroshan, Y., Pangrazio, G. and Pernechele, V. (2011), *Food and agricultural policy trends after the 2008 food security crisis: Renewed attention to agricultural development*, FAO, EASYPol Module 125, http://www.fao.org/docs/up/easypol/932/policy-trends_125en.pdf (accessed 27 Apr. 2017). See, for example, Saudi Arabia's programme to support domestic wheat production. USDA (2016), 'Saudi Arabia Grain and Feed Annual', https://gain.fas.usda.gov/Recent%20GAIN%20Publications/Grain%20and%20Feed%20Annual_Riyadh_Saudi%20Arabia_3-14-2016.pdf (accessed 23 Feb. 2017). For the UAE's investment in stocks, see Arnold, T. (2013), 'Ten wheat and rice silos that can feed the UAE for six months', *The National*, 4 August 2013, http://www.thenational.ae/business/industry-insights/economics/ten-wheat-and-rice-silos-that-can-feed-the-uae-for-six-months (accessed 17 Mar. 2017).
[276] Beer, E. (2014), 'Saudi Arabia commissions $132m grain facility in Al-Ahsa', *Food Navigator*, 30 May 2014, http://www.foodnavigator.com/Regions/Middle-East/Saudi-Arabia-commissions-132m-grain-facility-in-Al-Ahsa (accessed 31 Aug. 2016).
[277] Reuters (2015), 'Al Dahra aims to open UAE's Fujairah grain silos by January', Thomson Reuters Zawya, 13 November 2015, https://www.zawya.com/story/Al_Dahra_aims_to_open_UAEs_Fujairah_grain_silos_by_January-TR20151113nL8N1383SRX2 (accessed 31 Aug. 2016); Peel, M. (2013), 'Fujairah's importance grows amid Iran threat to Strait of Hormuz', *Financial Times*, 18 June 2013, http://www.ft.com/cms/s/0/09c50ae0-d4e7-11e2-9302-00144feab7de.html#axzz4Iu3tHo6I (accessed 31 Aug. 2016).

5.1.3 Increasing control over supply

The 2007–08 food price spike also led to a rise in overseas investment in farmland.[278] Much of this was no doubt a commercial response to rising commodity prices. However, the involvement of government-backed investment vehicles and state-owned enterprises indicated that some governments viewed these investments strategically, in effect as 'outsourced national production' that could be diverted to domestic markets when needed.

Many of the 'host' countries targeted for investment are poor and food-insecure themselves, so might conceivably close their ports to food exports during a systemic crisis

Such investments often failed to account for chokepoint risks. In essence, governments believed they held an implicit 'call option'[279] on the output of their investments and that this option could be exercised during a systemic crisis, thus enabling them to divert food from international markets to their home market. But this assumed that the food could be transported quickly through any interposing chokepoints. Many of the 'host' countries targeted for investment are poor and food-insecure themselves, so might conceivably close their ports to food exports during a systemic crisis. And political risks are not the only problem; poor infrastructure can also render ownership of overseas production less effective. For example, Gulf countries were quick to invest in agriculture in Africa (see Table 7),[280] but did not match this with investments to build resilient transport corridors linking these regions to the sea. Poor-quality and low-density road networks remain the primary conduit for agricultural exports in sub-Saharan Africa,[281] while bureaucratic inefficiencies and non-tariff trade barriers delay shipments and drive up transport and transaction costs.[282] Meanwhile, other GCC investments in Black Sea agriculture have merely increased the exposure of Gulf countries to the Turkish Straits and Suez Canal.

Governments have also sought greater control of supply further 'downstream', by establishing or expanding state-owned commodity trading houses. While these companies are run for profit, commercial considerations would presumably be subordinated to national security during a systemic crisis or major domestic supply shock, when supply would be diverted to the home market rather being made available to the highest bidder. Compared to investing in overseas production, the obvious advantage of this strategy is that it can provide the importing government with more flexibility in sourcing, allowing chokepoint exposure to be managed dynamically and responsively. Where they are also investing in production, these businesses are additionally investing in supply chain infrastructure, so reducing chokepoint risk in the process.

278 Deininger, K. and Byerlee, D. (2011), *Rising Global Interest in Farmland,* Washington, DC: World Bank, https://siteresources.worldbank.org/DEC/Resources/Rising-Global-Interest-in-Farmland.pdf (accessed 5 Apr. 2016).
279 A right, but not an obligation, to buy a specified quantity of a good at a specified price within a specified time frame.
280 Bailey, R. and Willoughby, R. (2013), *Edible Oil: Food Security in the Gulf*, Briefing Paper, London: Royal Institute of International Affairs, https://www.chathamhouse.org/sites/files/chathamhouse/public/Research/Energy,%20Environment%20and%20Development/bp1113edibleoil.pdf (accessed 11 Jul. 2016).
281 Gwilliam, K., Bofinger, H., Bullock, R., Carruthers, R., Kumar, A., Mundy, M., Nogales, A. and Sethi, K. (2011), *Africa's Transport Infrastructure: Mainstreaming Maintenance and Management,* Washington, DC: World Bank, http://documents.worldbank.org/curated/en/728801468191665263/Africas-transport-infrastructure-mainstreaming-maintenance-and-management (accessed 12 Apr. 2017).
282 Engel, J., Jouanjean, M.-A. and Awal, A. (2013), *The history, impact and political economy of barriers to food trade in sub-Saharan Africa: an analytical review*, ODI Report, https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/8803.pdf (accessed 12 Apr. 2017).

Table 7: Selected GCC investment holdings in African agricultural projects

Project location	Company or investment fund	Main foreign owner or investor	Base of foreign owner or investor	Size (ha)	Crop and/or activity	Project investment (US$ million)	Infrastructure quality (1–7, 7=best)		
							Road	*Rail*	*Port*
Mozambique	*Companhia do Vale do Rio Lúrio*	*National Holding*	*UAE*	*607,236*	*Cereals; oilseeds (in addition to cotton, sugar, livestock)*	*4,400*	*2.4*	*2.4*	*3.5*
Egypt	Jenat Agricultural Investment Company	Al Rajhi International for Investment	Saudi Arabia	10,000	Wheat; feed	n/a	3.0	2.6	4.3
Egypt	Al Dahra	Al Dahra	UAE	48,500	Wheat (in addition to potatoes and other unspecified crops)	n/a	3.0	2.6	4.3
Ethiopia	Saudi Star PLC	Al Muwakaba for Industrial Development & Overseas Commerce (MIDROC)	Saudi Arabia	124,000	Cereals; oilseeds (in addition to rice, oil palm, coffee, dairy, meat, livestock)	100	3.7	3.4	3.5
Ghana	Africa Atlantic Holdings	Africa Atlantic Holdings	UAE	10,947	Maize	n/a	3.5	1.8	3.7
Mauritania	Al Rajhi International Investment Company	Al Rajhi International for Investment	Saudi Arabia	31,000	Agribusiness (unspecified)	1,000	2.3	2.0	2.9
Nigeria	PJS Rice	PJS Rice	UAE	7,500	Rice	100	2.6	1.5	2.8
Sudan	Almarai Co.	Almarai Co.	Saudi Arabia	9,239	Maize; wheat	45.3	n/a	n/a	n/a
Sudan	Jenat Agricultural Investment Company	Al Rajhi International for Investment	Saudi Arabia	20,000	Maize; wheat (in addition to alfalfa)	n/a	n/a	n/a	n/a
Sudan	National Agricultural Development Co (NADEC)	National Agricultural Development Co (NADEC)	Saudi Arabia	25,000	Agribusiness (unspecified)	n/a	n/a	n/a	n/a
Sudan	*Al Dahra*	*Al Dahra*	*UAE*	*971,245*	*Maize; wheat (in addition to barley, cotton, hay, sugarcane, sunflowers, alfalfa)*	*10,000*	*n/a*	*n/a*	*n/a*

Note: Projects active as of 30 August 2016 (includes only those projects initiated after 2006; led by foreign investors; of 500 hectares or more); projects in italics are in negotiation. The letters 'n/a' indicate a lack of data.
Sources: Based on GRAIN (2016), 'The global farmland grab in 2016: how big, how bad?', https://www.grain.org/article/entries/5492-the-global-farmland-grab-in-2016-how-big-how-bad (accessed 25 Apr. 2017); Chatham House (2017), Chatham House Food Security Dashboard, with original data from Schwab, K. (ed.) (2016), *The Global Competitiveness Report 2016–2017*.

One such trading house is Saudi Arabia's state-owned Saudi Agricultural and Livestock Investment Company (SALIC), established in 2011. In addition to trading, its interests include supply chain logistics such as railways, shipping, storage and port operations. SALIC is seeking acquisitions to establish supply chains connecting Saudi Arabia with major crop-producing regions in North America, South America and the Black Sea.[283] South Korea has taken a similar step, with the establishment in 2011 of a state-owned trading company led by Korea Agro-Fisheries & Food Trade Corporation (KAFTC) and involving transport and logistics partners; the aim of the venture is to source up to 30 per cent of South Korea's grain imports directly from US farmers by 2020.[284]

The most prominent state-owned commodities trader, however, is the China National Cereals, Oils and Foodstuffs Corporation (COFCO). The company has grown through a string of major acquisitions to become one of the largest grain traders in the world. It is present in over 140 countries and has revenues in the region of US$62 billion[285] (by way of comparison, US giant Cargill's revenues were US$107 billion in 2016).[286] COFCO's recent deals have included the purchase of the agribusiness operations of Hong Kong-headquartered Noble Group, and the acquisition of Dutch trader Nidera. Like SALIC, COFCO is now focusing on establishing globally integrated supply chains as well as seeking acquisitions that include strategic assets, such as storage and export infrastructure in crop-producing regions in North America, South America and the Black Sea. This strategy of increasing operational control of supply chain assets mirrors that of private-sector commodities companies (see Box 11).

Major agricultural trading houses have targeted bottlenecks in crop-growing regions

Box 11: Private-sector responses to supply chain risk

The four major international agricultural trading houses – Archer Daniels Midland (ADM), Bunge, Cargill and Louis Dreyfus, which collectively account for an estimated 75–90 per cent of global trade in grain[287] – began vertically integrating before the 2007–08 global food price crisis as a means to capture value and increase security along the supply chain.[288] Their assets include grain terminals at ports, storage infrastructure and dry bulk shipping fleets.

The firms' infrastructure investments have targeted bottlenecks in major crop-growing regions. Cargill has recently expanded its investments in Russia to include grain storage facilities and elevators, and a share in an export terminal at Novorossiysk port, a major trans-shipment hub prone to back-ups.[289] Bunge and ADM have increased their investments

[283] SALIC (undated), 'Investment Destinations', http://www.salic.com/English/Agriculturalinputs/Pages/Investmentdestinations.aspx (accessed 18 Jun. 2017).
[284] Oliver, C. and Blas, J. (2011), 'Seoul plans US grain trading house', *Financial Times*, 10 January 2011, https://www.ft.com/content/b69c63dc-1ceb-11e0-8c86-00144feab49a (accessed 27 Apr. 2017).
[285] ChinaAg (2017), 'COFCO Group to Implement Mixed-Ownership Reforms Including IPOS and ESOPS', 3 March 2017, http://www.chinaag.org/2017/03/03/cofco-group-to-implement-mixed-ownership-reforms-including-ipos-and-esops/ (accessed 18 Jun. 2017).
[286] Singh, S. D. (2017), 'Cargill at odds with Trump as it warns on immigration, trade', *Sydney Morning Herald,* 5 February 2017, http://www.smh.com.au/business/world-business/cargill-at-odds-with-trump-as-it-warns-on-immigration-trade-20170205-gu5v93.html (accessed 23 May 2017).
[287] Lawrence, F. (2011), 'The global food crisis: ABCD of food – how the multinationals dominate trade', *Guardian*, 2 June 2011, https://www.theguardian.com/global-development/poverty-matters/2011/jun/02/abcd-food-giants-dominate-trade (accessed 24 Mar. 2017).
[288] Clapp, J. (2015), 'ABCD and beyond: From grain merchants to agricultural value chain managers', Section IV, Corporate Role in Food and Agriculture, Special Issue: Mapping the Global Food Landscape, *Canadian Food Studies,* 2(2): 126–132, http://canadianfoodstudies.uwaterloo.ca/index.php/cfs/article/download/84/105 (accessed 17 Mar. 2017).
[289] Glauben et al. (2014), *Eastern breadbasket obstructs its market and growth opportunities*.

in Ukraine over the past two years.[290] ADM and Cargill have invested in the expansion of Constanta, a deep-water port in Romania – grain exports from the port in August 2014 were up by 30 per cent on the previous year.[291]

Major agribusinesses are also increasing their footprint in Brazil: in 2015, Cargill and Louis Dreyfus Commodities won the first of many auctions for private operation of state-owned ports, committing to the management of Santos port in the south of the country for a period of 25 years;[292] ADM is expanding its own terminal at Santos port;[293] Cargill has constructed a soybean export terminal at the port of Santarém in the north as an alternative export route; Bunge and ADM also have plans to open soybean export terminals in the north.[294]

China is actively seeking to reduce its exposure to critical chokepoints by reshaping global supply chains themselves

In an arguably even wider-reaching development, China is actively seeking to reduce its exposure to critical chokepoints by reshaping global supply chains themselves. The government's 'Belt and Road' initiative spans multiple continents and many large-scale infrastructure developments. It encompasses planned investments in railways, roads, waterways and ports – including in and around ports and inland railways in the Black Sea region. To date, these projects include a new grain trans-shipment terminal in Mykolaiv on the Black Sea, constructed by COFCO-owned Noble Agri, and the acquisition of the Kumport container terminal in Istanbul.[295] The latter is intended to facilitate transmodal transportation (incorporating more than one mode of transport) from Xi'An in China along the Silk Road Economic Belt to Moscow, bypassing the congested railways to the north of the Black Sea. Chinese support for a freight railway and ferry service linking Ukraine via the Black Sea, the Caspian Sea and Kazakhstan to China will likely further ease pressure on the region's strained transport network.[296]

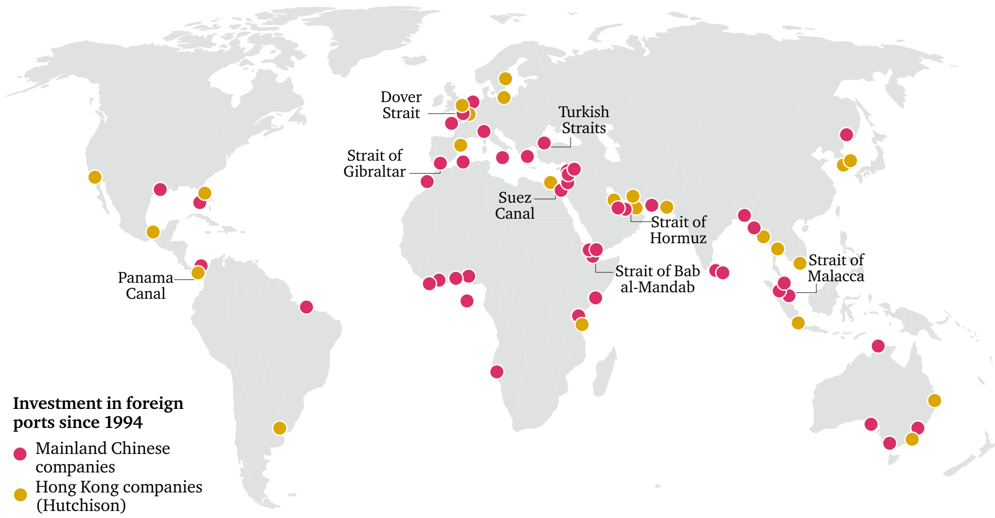
Beyond 'Belt and Road' projects, Chinese-backed infrastructure developments targeted specifically at circumventing existing trade chokepoints also abound. While there is a willingness in China to use established economic structures, such as market-driven processes, to secure and ship supply, there is also a parallel drive to bypass those structures and create new relationships that are bilateral and perceived to be easier to control. As mentioned in Chapter 2, a US$60 billion project to link Brazil's Atlantic coast with Peru's Pacific coast by rail will, when completed, offer a secondary export route for soybean destined for China that both avoids the clogged ports of southern

[290] Mousseau, F. (2015), 'West's agri-giants snap up Ukraine', *Asia Times Online*, 28 January 2015, http://www.atimes.com/atimes/Central_Asia/CEN-02-280115.html (accessed 8 Mar. 2017); Bunge, J. (2014), 'Grain Companies Say They See No Significant Ukraine Impact: Investors' Concerns Push Wheat Futures Higher, Lower Companies' Shares', *Wall Street Journal,* 3 March 2014, https://www.wsj.com/articles/SB10001424052702304585004579417523345324430 (accessed 8 Mar. 2017).
[291] Ruitenberg, R. (2014), 'Cargill's Black Sea Stop is Booming 2,600-Year-Old Port', Bloomberg, 17 October 2014, https://www.bloomberg.com/news/articles/2014-10-17/cargill-s-black-sea-stop-is-booming-2-600-year-old-port (accessed 28 Apr. 2017).
[292] Jordão, P. (2015), 'Louis Dreyfus, Cargill, Fibria win Brazil port areas', Reuters, 9 December 2015, http://www.reuters.com/article/brazil-ports-idUSL1N13Y0Q120151209?feedName=companyNews&feedType=RSS&type=companyNews (accessed 8 Mar. 2017).
[293] ADM (2016), 'ADM Expanding, Modernizing Brazilian Port', press release, 5 April 2016, http://www.adm.com/en-US/news/_layouts/PressReleaseDetail.aspx?ID=715 (accessed 8 Mar. 2017).
[294] Bonato, G. and Stauffer, C. (2013), 'In Brazil, a new road to the Amazon offers grain export relief', Reuters, 16 October 2013, Reuters, http://uk.reuters.com/article/brazil-route-idUKL2N0HJ1W020131016 (accessed 8 Mar. 2017).
[295] Tan, W. Z. (2015), 'Cosco and China Merchants complete Turkish terminal acquisition', *Lloyd's Loading List*, 19 November 2015, http://www.lloydsloadinglist.com/freight-directory/news/Cosco-and-China-Merchants-complete-Turkish-terminal-acquisition/64818.htm#.V8agQKLU3cs (accessed 31 Aug. 2016).
[296] Mykal, O. (2016), 'Why China Is Interested in Ukraine', *The Diplomat*, 10 March 2016, http://thediplomat.com/2016/03/why-china-is-interested-in-ukraine (accessed 31 Aug. 2016).

Brazil and bypasses the Panama Canal.[297] Plans were also previously in place for a canal, funded by a business magnate from Hong Kong, that would run through Nicaragua and rival the Panama Canal as a link between the Atlantic and Pacific oceans. The Chinese government has distanced itself from the project since construction stalled at the end of 2015. Nonetheless, the diversification of trade routes between South America and China remains in line with China's wider interests in the region.[298]

China's investments in ports in countries around the world have been among its most controversial – perhaps unsurprisingly given their strategic importance and the potential for 'dual use' as naval bases. Analysis by the *Financial Times* identified several ports where commercial investments have preceded military activity by the Chinese, whether in India, Greece or Djibouti (see Figure 25). On the other hand, others have argued that even if these evolve into military outposts, they are more likely to be used as logistical support for non-traditional military operations such as counter-piracy or evacuations than to project hard power.

Figure 25: Chinese ownership of overseas ports



Source: Adapted from Kynge, J., Campbell, C., Kazmin, A. and Bokhari, F. (2017), 'How China rules the waves', *Financial Times*, 12 January 2017, https://ig.ft.com/sites/china-ports (accessed 27 Mar. 2017); original Kynge et al. map based on data from King's College, London; FT research; CIA.

China is also a major investor in Brazil's ambitious programme to upgrade and expand domestic transport infrastructure. In partnership with the Brazilian government, China has put up three-quarters of the capital for a new US$20 billion bilateral infrastructure fund to invest in transport and logistics operations; the fund has a particular focus on railways to link Brazil's soybean- and maize-growing belts to the coast.[299]

[297] Ernst & Young, China (2015), *Riding the Silk Road: China sees outbound investment boom – Outlook for China's outward foreign direct investment*, March 2015, http://www.ey.com/Publication/vwLUAssets/ey-china-outbound-investment-report-en/$FILE/ey-china-outbound-investment-report-en.pdf (accessed 23 May 2017).
[298] Dollar, D. (2017), *China's Investment in Latin America,* Geoeconomics and Global Issues Paper 4, January 2017, Washington, DC: Brookings Institution, https://www.brookings.edu/wp-content/uploads/2017/01/fp_201701_china_investment_lat_am.pdf (accessed 8 Mar. 2017).
[299] Soto, A. (2017), 'Brazil expects $20 bln fund with China to begin financing projects by March', Reuters*,* 9 January 2017, http://www.reuters.com/article/brazil-china-infrastructure-idUSL1N1EZ0PJ (accessed 27 Apr. 2017).

5.2 The governance gap

Ensuring the maintenance and unimpeded operation of systemic chokepoints can be considered a global good, given its importance to international food security (and to trade generally). However, chokepoints fall under the jurisdiction of governments: inland and coastal chokepoints and interoceanic canals (i.e. Panama and Suez) lie within the territory of nation states; maritime straits are controlled by the littoral states (though, where defined as international straits, these are also governed by international law under UNCLOS).

5.2.1 National infrastructure

The operation and maintenance of interoceanic canals and critical infrastructure in major crop-growing regions are, in effect, hostage to local context: to political decisions, policies, macroeconomic conditions, weather, climate and security dynamics in the individual countries concerned (see Section 3.1). The chronic underinvestment in infrastructure in producer countries, as outlined in Chapter 2, is a case in point; another is the unilateral imposition of export restrictions at Black Sea chokepoints in the recent past.

There is a global infrastructure financing gap estimated at US$250 billion a year through to 2040

In essence, there is a mismatch between risk exposure on the part of import-dependent countries – particularly LIFDCs – which are unable to address the risk at source; and risk ownership on the part of infrastructure-controlling governments, which may be unwilling to address the risk. In some instances, cooperation can address these failures. Chinese investment in Brazilian infrastructure at inland and coastal chokepoints is an obvious example. In other cases, such as the lack of rules against ad hoc export restrictions, new governance arrangements are required.

Infrastructure deficits are by no means confined to major crop producers and exporters, moreover. There is a global infrastructure financing gap – a shortfall between the funding available and the funding needed – estimated at US$250 billion a year through to 2040.[300] Even where infrastructure investment is occurring, national policies too often fail to properly account for climate risks. A 2016 survey of OECD countries found that, with very few exceptions, climate risks to infrastructure receive minimal attention from governments in industrialized economies;[301] and that frameworks for corporate reporting of climate risks – in so far as they affect infrastructure and operations – also remain largely voluntary.[302] Despite its importance, climate-compatible infrastructure has also received remarkably little attention at the international level. Although a number of multilateral development banks now explicitly consider climate risks in their lending, there is little consistency; best practice 'remains patchy', according to a recent paper from

[300] Woetzel, J., Garemo, N., Mischke, J., Hjerpe, M. and Palter, R. (2016), *Bridging Global Infrastructure Gaps*, McKinsey Global Institute, June 2016, http://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/bridging-global-infrastructure-gaps (accessed 24 Feb. 2017).
[301] OECD (2016), *The role of government in making infrastructure investment climate resilient*.
[302] Ibid.

the Global Commission on the Economy and Climate's 'New Climate Economy' project.[303] Recent efforts by the G20, through its Global Infrastructure Hub, to close the infrastructure gap ignore climate change.

5.2.2 Maritime straits

The criticality of maritime straits to food, energy and global trade in general means they have very high strategic value. Unlike national infrastructure, maritime chokepoints are a global good; this is reflected in the international governance arrangements for them. Specifically, UNCLOS establishes right of passage for 'international navigation' in straits, and militates against the unilateral closure of straits by littoral states.[304] UNCLOS has not been universally ratified, however. Among littoral states, notable exceptions are Iran (Strait of Hormuz), Eritrea (Strait of Bab al-Mandab) and Turkey (Turkish Straits, although these straits are covered by an agreement pre-dating UNCLOS). Among user states, the most notable exception is the US. Beyond wider ratification of UNCLOS, proposals for strengthening the governance of straits include seeking political declarations from user and littoral states to confirm rights of passage, and even drafting a new convention dealing specifically with maritime chokepoints, although this would be politically difficult to achieve.[305]

However, as Chapter 3 demonstrated, maritime chokepoints may be strategic targets for non-state actors as well as states, in particular terrorist groups and insurgents. Interstate cooperation on intelligence-sharing and policing will be necessary to address this threat, possibly building on models successfully used to combat piracy.

5.2.3 Preparedness

Strategies that seek to mitigate risks at source by ensuring the maintenance and unimpeded operation of systemic chokepoints constitute risk reduction measures. However, risk reduction needs to be complemented by measures to prepare for inevitable chokepoint disruptions. States can pursue such strategies individually, of course: the earlier examples of strategic stock-building and state-led investments in land, logistics and trading operations are testament to this. However, these moves hint at readiness for uncoordinated unilateralism rather than a collective response. This means that a major market failure or dislocation of trade could lead to states scrambling to secure supply, competing against each other and deepening the crisis as they do so.

Collective arrangements can reduce costs and help tip the balance away from competition towards cooperation. For example, governments in Asia recently established the ASEAN Plus Three Emergency Rice Reserve, under which participating governments commit to making available an earmarked portion of their national stocks to meet the needs of other member countries in an emergency.[306] Modelling suggests that

[303] Rydge, J., Jacobs, M. and Granoff, I. (2015), 'Ensuring new infrastructure is climate-smart', New Climate Economy, http://newclimateeconomy.report/2015/wp-content/uploads/sites/3/2015/10/Ensuring-infrastructure-is-climate-smart.pdf, (accessed 27 Apr. 2017).
[304] Emmerson and Stevens (2012), *Maritime Choke Points and the Global Energy System*.
[305] Ibid.
[306] ASEAN Plus Three Emergency Rice Reserve, www.apterr.org (accessed 9 Mar. 2017).

diversification of supply risk in this way reduces the overall size of the reserve needed, thereby lowering costs for all.[307]

Perhaps more valuable than cost savings are the enhanced trust, mutual accountability and information-sharing that come with jointly managing a common reserve and agreeing rules for emergency sharing. A similar model, under the governance of the International Energy Agency (IEA), has been in place in oil markets since the oil crises of the 1970s, though concerns persist about 'free-riding' and whether sharing would actually happen in a true worst-case emergency (see Box 12).

Box 12: Lessons from the energy sector: oil and security of supply

Professor Paul Stevens, Chatham House

Historically, concerns over security of oil supply have been twofold. Firstly, refiners have been concerned with guaranteeing their supply of crude oil: the cost structure of refining is such that refineries need to operate at full capacity if they are to be profitable; inability to secure crude supplies seriously threatens their ability to do so. Secondly, consumers have been concerned with securing oil products to support economic activity: the stock of energy-using appliances burning oil is fixed, at least in the short term, meaning that there is limited potential to switch to alternative fuels in the case of a shortfall.

Before the 1970s, both concerns could be managed. Refiners moved towards vertical integration of their supply chains: the large international oil companies (IOCs) owned and managed their own crude oil sources and refineries. Consumers opted to boost storage capacity. The system worked well. While there were three major disruptions – the 1951 Iranian nationalizations, the 1956 Suez crisis, and the 1967 Six-Day War between the Arabs and Israelis – none gave rise to any obvious physical shortage of either crude oil or oil products; IOCs managed the problem through their own logistics systems.

In the 1970s, two developments changed the situation. The first was the nationalization by producer-country governments of the crude-producing affiliates of the IOCs, which undid much of the IOCs' vertical integration. The second was the Arab oil embargo and the first oil price shock in 1973–74, which raised the spectre of potentially significant, long-term, politically induced supply disruptions. At the same time, an increasingly fragile political situation in the Middle East heightened concerns about the likely supply impacts of a disruption to the Strait of Hormuz, Strait of Bab al-Mandab and/or Suez Canal.[308]

In this context, there was a growing consensus that ensuring security of supply would be best served by a coordinated response founded on increased storage. The first step was an initiative launched by Henry Kissinger, then US secretary of state, in November 1974 to create the International Energy Agency (IEA). Central to the IEA was its Emergency Sharing Mechanism, which required member states to maintain 90 days' worth of oil (crude and products) in storage. A series of rules was then laid down to govern the terms under which stocks would be released.

In 1978, the US established its Strategic Petroleum Reserve (SPR), building up large crude storage capacity (in excess of the IEA minimum requirement) in salt caverns in Louisiana. The creation of the SPR sparked much discussion about possible 'free-riding'

[307] Nujahid, I. and Kornher, L. (2016), 'ASEAN Food Reserve and Trade: Review and Prospect', in Kalkuhl, M., von Braun, J. and Torero, M. (eds) (2016), *Food Price Volatility and its Implications for Food Security and Policy,* http://link.springer.com/chapter/10.1007/978-3-319-28201-5_17/fulltext.html (accessed 27 Apr. 2017).
[308] Emmerson and Stevens (2012), *Maritime Choke Points and the Global Energy System*.

While the effectiveness of the IEA and other mechanisms in oil markets is much debated, industry insiders agree that any emergency sharing scheme would fall to pieces in the event of a disruption as serious as closure of the Strait of Hormuz

by other countries;[309] since oil was traded in a global market, any release of stocks from the SPR would dampen price spikes internationally, providing a benefit to other consuming countries at no cost.

These mechanisms have been tested on only a few occasions. The first was the shortfall of crude oil during the Iranian revolution and the Iran–Iraq war (though at the time the SPR was not yet operational). The IEA decided not to invoke the Emergency Sharing Mechanism; the result was an every-man-for-himself situation of intense competition between American and Japanese companies, prompting a second oil price shock. The second test was the loss of Iraqi and Kuwaiti crude supply following Iraq's 1990 invasion of Kuwait. The price effects of this were initially dampened by the action of Saudi Arabia, which pushed its significant spare capacity into the market. But at the start of the campaign to liberate Kuwait, in 1991, the IEA also released its stocks; this had the unintended effect of aggravating price volatility. The third test came in 2005 when Hurricane Katrina struck oil logistics hubs along the Gulf of Mexico. The IEA announced a stock release, but, since there was no actual shortage of supply, there were few takers of the crude on offer.

While the effectiveness of the IEA and other mechanisms in oil markets is much debated in the literature, industry insiders tend to agree that any emergency sharing scheme would fall to pieces in the event of a disruption as serious as closure of the Strait of Hormuz. In their view, when push comes to shove, national interests trump efforts to manage global market stability – a conclusion that seems more sure in an era of US foreign policy that emphasizes the idea of 'America First'.

5.3 Conclusions

The experience of 2007 to 2011 has shaped national responses to food supply risk, such that the priority remains to manage price volatility on the understanding that international markets will adjust to any temporary shortfall in food availability. Few governments have taken steps to mitigate the risk of physical supply dislocations, though China is a marked exception in this respect. Investment in the infrastructure that supports international food trade is inadequate or lacking almost across the board, and few provisions exist for protecting global strategic interests as affected by the operation of nationally owned and operated chokepoints.

As reliance on international food trade increases and hazards to the operation of trade chokepoints intensify, there is a need for cooperative approaches to infrastructure investment, chokepoint risk mitigation and preparedness for worst-case disruption scenarios. Cost- and risk-sharing arrangements will be key to enabling much-needed risk management strategies, many of which will be capital-intensive and long-running. These strategies will also need to be adaptive to keep pace with evolving hazards and vulnerabilities, and to reflect shifts in the patterns of global food trade.

[309] More recently, other countries – notably China – have been building up their strategic reserves, helped by the oil price collapse that struck in June 2014. Bloomberg (2016), 'Oil Bulls Beware Because China's Almost Done Amassing Crude', Bloomberg News, 1 July 2016, https://www.bloomberg.com/news/articles/2016-06-30/oil-bulls-beware-because-china-s-almost-done-amassing-crude (accessed 28 Apr. 2017).

Chokepoint Risk 'Hotspots'

Each of the trade chokepoints discussed in this report poses a degree of risk to global food security, and requires management by governments, infrastructure operators, investors and insurers, as well as a range of other private and non-governmental stakeholders. Nevertheless, there are a number of hotspots of heightened risk, the management of which should be a priority for relevant national actors and the international community. These critical areas of risk are located in the three major supplier regions – the US, Brazil and the Black Sea – and in two of the most chokepoint-dependent and food-insecure regions – the Middle East and North Africa (MENA), and East Africa.

US inland waterways, rail network and Gulf Coast ports

The scale both of the physical inland transport networks and of the investment gap in the US is such that its critical grain export arteries are a major point of liability in the global system. Despite considerable understanding of the infrastructural, institutional and climate risks that threaten the reliability and integrity of the US's locks, dams and railways, and notwithstanding ambitious investment plans, the slow pace and poor coordination of maintenance and modernization of these facilities indicate the increasing probability of disruption. Both the Gulf Coast ports and the waterway and rail networks linking Midwest producers to these ports are highly exposed to climate hazards: a number of weather-induced high-impact disruptions have already been seen, and climate stresses are expected to worsen over the coming decades.

While the US's share of global grain exports is likely to fall as Black Sea and South American producers increase their global footprint, many parts of the US waterway and rail networks are already near or at full capacity. This means that even marginal increases in US export volumes are likely to have an exponential impact on the severity of congestion and frequency of blockages, with corresponding implications for the international market impact of an acute disruption.

Brazil's inland road network and southern ports

Brazil's spectacular rise as a global supplier of soybean and, increasingly, maize has not been matched by investment in its coastal export infrastructure. Ports in the south are operating at near full capacity, while shipment to new export terminals coming online in the north of the country is hindered by the poor condition of the country's roads.[310] Its ports rank 114th out of 137 (137 being the poorest ranking) in terms of infrastructure quality.[311] The prospect of rising sea levels poses a significant threat to the country's low-lying coastal plains, which are already afflicted by surface flooding and landslides.

[310] Freitas, T. (2017), 'Mired in Mud, Brazil's Unpaved Roads Delay Farming Promise', Bloomberg Markets, 4 January 2017, https://www.bloomberg.com/news/articles/2017-01-04/mired-in-mud-brazil-s-unpaved-roads-delay-agricultural-promise (accessed 23 May 2017); Soybean & Corn Advisor (2017), '"Northern Arc" of Ports will Export 23.8% of Brazil's Grain Exports', 14 February 2017, http://www.soybeansandcorn.com/news/Feb14_17-Northern-Arc-of-Ports-will-Export-23_8-of-Brazils-Grain-Exports (accessed 23 May 2017).
[311] Schwab (ed.) (2016), *The Global Competitiveness Report 2016–2017*.

Transport costs remain high, and a number of serious and sustained road traffic tailbacks have been seen both at seaports and inland in recent years. Political turmoil risks stymying the ambitious infrastructure development projects under way, and deterring would-be private investors in additional capacity and modernized facilities. As Brazil is the largest global exporter of soybean, stoppages in supply from the country would likely have a material impact on world soybean prices. The country's importance as a supplier to China further heightens the risk of system-wide reverberations should a disaster strike the seaports in southern Brazil, as a sudden spike in demand for US soybean could push the US's inland infrastructure to breaking point.

Black Sea railways and ports

The events of the Arab Spring offer a striking illustration of the potential cascading effects of a chokepoint disruption in the Black Sea region

The inland and coastal chokepoints of the Black Sea region are the most volatile of any of the 14 chokepoints discussed in this report. Conflict in Crimea is ongoing, with collateral impacts on the movement of grain and other cargo; diplomatic tensions are high over the wars in Syria and Yemen; and trade relations with the EU remain unstable. The governments of Russia, Ukraine and Kazakhstan have proved willing to impose both official and de facto export restrictions when domestic supply shortages or price spikes loom.

Investment in rail infrastructure is sorely lacking. While the region's ports are benefiting from increased private investment, storage and trans-shipment infrastructure remains poor and bureaucratic inefficiencies are endemic. The events of the Arab Spring offer a striking illustration of the potential cascading effects of a chokepoint disruption in the Black Sea region; as Russia and Ukraine strengthen their positions as major global sources of wheat, the spread and intensity of these effects are likely to increase.

MENA region and the Strait of Bab al-Mandab

Food-deficit countries in the MENA region are particularly exposed to chokepoint disruption owing to their geographic position and high degree of import dependence. Maritime chokepoints in the region are of high criticality: sustained interruption to trade through the Strait of Gibraltar, Turkish Straits, Suez Canal, Strait of Bab al-Mandab or Strait of Hormuz could prompt import delays of several weeks. Disruptive hazards to these maritime chokepoints, and to the Black Sea railways and ports on which MENA countries also rely heavily, are myriad and in many cases worsening. The capacity of MENA countries to withstand a major disruption is severely constrained by widespread instability and armed conflict and by poor overland infrastructure.

The Strait of Bab al-Mandab is a highly critical access route for import-dependent countries in both the Horn of Africa and (together with the Strait of Hormuz) the Gulf. A number of attacks on vessels passing through the strait have been reported since late 2016, as the conflict in Yemen and tensions between Saudi Arabia and Iran have spilled over into surrounding waters.[312] With humanitarian aid vessels reportedly being obstructed by both Houthis and the anti-Houthi coalition, critical

[312] Vaughan, J. and Henderson, S. (2017), 'Bab al-Mandab Shipping Chokepoint Under Threat', The Washington Institute, 1 March 2017, http://www.washingtoninstitute.org/policy-analysis/view/bab-al-mandab-shipping-chokepoint-under-threat (accessed 27 Apr. 2017).

food supplies are failing to reach Yemen and supply to famine-stricken populations in East Africa is under threat (a similar situation occurred in 2011 when Somali piracy hindered the delivery of food aid to Somalia).[313, 314] The high costs of war risk insurance for vessels transiting the Strait of Bab al-Mandab and the Gulf of Aden, and the increased transport costs for those that reroute around the Cape of Good Hope, may also contribute to higher food prices for any importing countries still able to access international shipments.[315]

East Africa

The low-income food-deficit countries (LIFDCs) of the Horn of Africa and the wider East Africa region are among the most vulnerable to chokepoint disruption. Levels of malnutrition, household spending on food, and government spending on food imports in these countries are high, and much of the region is in the throes of a famine or acute food emergency. Armed conflict and poor infrastructure make cross-border food distribution high-risk, while increased terrorist activity in the region and the pervasive threat of piracy in Somali waters threaten the security of emergency food shipments. The region is highly dependent both on maritime chokepoints and on at-risk inland and coastal chokepoints in the Black Sea.

[313] Mbekeani, K. K. and Ncube, M. (2011), *Economic Impact of Maritime Piracy*, Africa Economic Brief, 2(10), African Development Bank, https://www.afdb.org/en/documents/document/africa-economic-brief-economic-impact-of-maritime-piracy-24575 (accessed 27 Mar. 2017).
[314] Saul, J. and Paul, K. (2017), 'Escalation in ship attacks pushes Yemen towards starvation', Reuters UK, 6 March 2017, http://uk.reuters.com/article/uk-yemen-security-maritime-analysis-idUKKBN16D161 (accessed 27 Apr. 2017).
[315] Bowden, A., Hurlburt, K., Aloyo, E., Marts, C. and Lee, A. (2010), *The Economic Cost of Maritime Piracy*, One Earth Future Working Paper, December 2010, http://oceansbeyondpiracy.org/sites/default/files/attachments/The%20Economic%20Cost%20of%20Piracy%20Full%20Report.pdf (accessed 27 Apr. 2017); Mbekeani and Ncube (2011), *Economic Impact of Maritime Piracy*.

6. Conclusions and Recommendations

Below we outline key conclusions from our analysis and propose five priority areas for action at national and international level to manage chokepoint risk to food security.

6.1 Key conclusions

6.1.1 Trade chokepoints are of increasing systemic importance to global food security

Maritime chokepoints will become increasingly integral to meeting global food supply as population growth, shifting dietary preferences, bioenergy expansion and slowing improvements in crop yields drive up demand for imported grain. Climate change will further widen the gap between food surpluses in centres of supply and deficits in centres of demand, spurring the movement of larger volumes of food around the world. At the same time, loss of soil fertility and more intense cultivation of cropland will likely heighten reliance among producers around the world on internationally traded fertilizers.

On current trends, dependence on key infrastructure in crop-exporting regions and on the maritime chokepoints that punctuate international shipping lanes will continue to rise

Increasing interconnections between producers in South America and consumer markets in Asia – and particularly China – are exerting pressure on the capacity of the Panama Canal and Strait of Malacca. Meanwhile, the Black Sea's rapidly growing importance as a supplier of wheat to the MENA region and Asia is driving up demand for capacity on railways and ports in Russia and Ukraine, and in the Turkish Straits.

Technological disruptions that radically alter food production methods and patterns of demand could significantly reduce systemic reliance on today's trade chokepoints, but are hard to predict. The potential opening of new sea lanes in the Arctic due to climate change is unlikely to relieve pressure on existing shipping routes before the second half of the century. On current trends, dependence on key infrastructure in crop-exporting regions and on the maritime chokepoints that punctuate international shipping lanes will continue to rise.

6.1.2 Chokepoint risk to food security is increasing

Rising trade volumes, increasing dependence on imports among food-deficit countries, underinvestment, weak governance, climate change and emerging disruptive hazards together make chokepoint disruptions – both small-scale and large-scale – increasingly likely.

While the Panama Canal and Suez Canal should prove relatively resilient to rising trade volumes, maritime straits and coastal and inland chokepoints are likely to feel the strain of greater transit numbers and larger vessels. More intense activity will exacerbate the impacts of any failures or blockages, and could well drive up the number of such incidents if resources to boost capacity and resilience are lacking.

Climate change will have a compounding effect on chokepoint risk, increasing the probability of both isolated and multiple, concurrent weather-induced disturbances. Higher atmospheric and ocean temperatures will compound the risk of drought, heatwaves and tropical cyclones, while rising sea levels will bring more frequent and damaging storm surges. Direct and indirect climate impacts will constrain the responsiveness and coping capacity of import-dependent countries, heightening their vulnerability to chokepoint disruption.

Political and security hazards also look likely to become more severe. Several trade chokepoints of global importance are located in regions where intra- or interstate tensions are escalating. These include the Suez Canal, the straits of Bab al-Mandab and Hormuz, the Turkish Straits, the Black Sea ports and the Strait of Malacca. Climate migration and conflicts over land and water are likely to become increasingly common in a resource-stressed world.

6.1.3 Robust risk management policies and initiatives are urgently needed

Food security assessments continue to focus primarily on national conditions, overlooking risks higher up the supply chain. Analysis of the risks arising from increasing market interconnectedness and growing reliance on trade is in its infancy. More data are needed on country-level reliance on trade chokepoints, and on the capacity and risk exposure of critical trade infrastructure.

More data are needed on country-level reliance on trade chokepoints, and on the capacity and risk exposure of critical trade infrastructure

While chokepoint interruptions threaten to exacerbate price rises and hinder the delivery of grain and fertilizer supply under both normal and emergency conditions, no international provisions are in place to protect the movement of critical food shipments or to coordinate the international response in the case of a high-impact supply disruption.

Investment in infrastructure lags demand growth: critical networks in major crop-producing regions are weak and ageing, and extra capacity is urgently needed. Insufficient investment is not only an issue for low-income countries. Fiscal constraints, bureaucratic inefficiencies and the vagaries of national politics have propagated infrastructural deficiencies of systemic consequence in the US, Brazil and the Black Sea exporters. Additionally, in the case of Russia and Ukraine, armed conflict has contributed to these deficiencies.

6.2 Recommendations

Managing chokepoint risk will require a range of interventions to build the resilience of trade chokepoints and chokepoint-dependent communities, reduce vulnerability to chokepoint disruption, and prepare for the impacts of interruption. The nature of necessary interventions will differ across geographies and national settings: for some, chokepoint risk may best be mitigated through investment in alternative supply lines; for others, dependence on a particular chokepoint may be unavoidable, in which case preparing for future shocks and reducing vulnerability at national and household level becomes the priority.

The report makes the following recommendations:

6.2.1 Integrate chokepoint analysis into mainstream risk management and security planning

Critical food security corridors could be identified by the United Nations. Whether under the auspices of UNCLOS, UN-Oceans or the WFP, this designation could help facilitate memoranda of understanding (MoUs) between the littoral states of globally important maritime chokepoints to protect critical food security corridors as far as possible, prioritizing food aid shipments in the event of a natural or man-made disruption. Under such MoUs, heads of state would commit to granting all food-carrying vessels passage through contested waters, allowing such ships to be escorted by WFP vessels, and prioritizing food aid shipments during the recovery period.

Government agencies should assess exposure and vulnerability to chokepoint risk at the national and subnational levels – working with international organizations such as the World Bank and UN Food and Agriculture Organization (FAO), and with donor agencies where appropriate. These assessments should aim to address the following questions:

- What is the reliance on imports via trade chokepoints to meet domestic demand?
- Are alternative supply sources available? If so, are these also reliant on trade chokepoints?
- How exposed are the relevant chokepoints to disruptive hazards?
- What, if any, contingency plans are in place to assist vulnerable segments of the national population in the event of a sudden supply disruption?

Donors could work with national governments to **develop and fund infrastructural disaster resilience strategies** to address the risk of disruption to national and global food supply chains. Such plans should involve the full range of stakeholders likely to be either directly affected by the event or directly involved in the response, and should identify roles and responsibilities to ensure effective coordination.[316] These could be tested through simulation exercises, to deepen understanding of practical and political challenges. They could consider how critical shipments of goods and commodities – including, though not necessarily limited to, food – would be prioritized in the event of a major disruption to supply.

National governments with expertise in mitigating or responding to disruptions should aim to share this knowledge with risk owners. For example, response and recovery procedures developed in the US following the devastation of Hurricane Katrina could form the basis of an international working group. Such a group would bring together US coastal authorities and emergency services, and their counterparts from other climate-vulnerable coastal hubs, to support and inform the development of national and site-specific contingency strategies.

Chokepoint reliance should be incorporated in comparative risk assessments and indicators of food insecurity by organizations that provide these services – such as the FAO,[317] the World Bank,[318] FEWS NET,[319] the Economist Intelligence Unit[320] and Maplecroft.[321]

[316] Boin, A. and McConnell, A. (2007), 'Preparing for Critical Infrastructure Breakdowns: The Limits of Crisis Management and the Need for Resilience', *Journal of Contingencies and Crisis Management*, 15(1): 50–59, doi: 10.1111/j.1468-5973.2007.00504.x (accessed 26 Apr. 2017); Leavitt, W. M. and Kiefer, J. J. (2006), 'Infrastructure Interdependency and the Creation of a Normal Disaster: The Case of Hurricane Katrina and the City of New Orleans', *Public Works Management & Policy*, 10(4): 306–314, doi: 10.1177/1087724X06289055 (accessed 26 Apr. 2017).
[317] FAO (2015), *The State of Food Insecurity in the World*, http://www.fao.org/3/a-i4646e.pdf (accessed 28 Apr. 2017).
[318] World Bank (undated), Databank, 'Agricultural & Rural Development', http://data.worldbank.org/topic/agriculture-and-rural-development?view=chart and 'Health', http://data.worldbank.org/topic/health?view=chart (accessed 28 Apr. 2017).
[319] FEWS NET, https://www.fews.net (accessed 18 Jun. 2017).
[320] Economist Intelligence Unit (undated), 'Global Food Security Index', http://foodsecurityindex.eiu.com (accessed 28 Apr. 2017).
[321] Verisk Maplecroft (2010), 'Latest product news: Risk calculators and dashboards', https://www.maplecroft.com/about/news/food-security.html (accessed 28 Apr. 2017).

6.2.2 Invest in infrastructure to ensure future food security

An international taskforce on climate-compatible infrastructure should be established under the G20, building on the work of the Global Infrastructure Hub and the Task Force on Climate-related Financial Disclosures (Financial Stability Board).[322] It would seek to promote coordinated fiscal stimulus policies, as a means to close the infrastructure financing gap while boosting the impact of such policies on economic growth and reducing the risk of adverse market sentiment.[323] More specifically, the taskforce would:

- Develop common principles for low-carbon, climate-resilient infrastructure policies;
- Agree guidelines and standards to inform infrastructure decisions at the planning, financing and construction phases of infrastructure development;
- Make recommendations for how these common principles, guidelines and standards can be entrenched in mainstream policy through, for example, harmonization of multilateral development bank approaches, new voluntary standards and national regulations;
- Examine the risks to the financial system from climate-related critical infrastructure failure and make recommendations for how these risks should be evaluated and managed;
- Quantify the global public services provided by major national critical infrastructure assets and develop recommendations for the mobilization of multinational funding or bilateral partnerships to invest in their resilience; and
- Advise on priority areas for multilateral development bank funding and private investment in existing chokepoints, secondary and tertiary trade hubs, and transport routes.

Independent infrastructure committees should be established at national level to advise on investment and policy decisions relating to major transport infrastructure. These committees would ideally cut across ministerial siloes and operate outside of parliamentary cycles. Their remit could be to assess and respond to long-term risks to infrastructural resilience. Following the example of the Committee on Climate Change in the UK, national governments should act on the recommendations of these committees or offer a full explanation as to why they do not plan to do so.

Investments by multilateral development banks in food-deficit countries should prioritize projects that diversify food supply sources, whether through the establishment of regional trans-shipment hubs, the development of regional strategic reserves, or investment in intermodal domestic transport networks. These plans should aim to improve connectivity and market access across sectors, including

[322] Financial Stability Board's Task Force on Climate-related Financial Disclosures (2016), *Recommendations of the Task Force on Climate-related Financial Disclosures*; and (2016), *Annex: Implementing the Recommendations of the TCFD*, https://www.fsb-tcfd.org/publications (accessed 24 Apr. 2017).
[323] Pickford, S. (2016), *Global Risks and the Challenges for G20 Coordination: A Growth Agenda for China's 2016 Presidency*, Research Paper, London: Royal Institute of International Affairs, https://www.chathamhouse.org/publication/global-risks-and-challenges-g20-coordination-growth-agenda-chinas-2016-presidency (accessed 28 Apr. 2017).

in food trade, both to compensate for the high sunk costs of major infrastructural developments and to avoid a proliferation of single-purpose 'enclave' projects.[324]

In countries where state-owned infrastructure is failing – including Russia, Ukraine and the US – governments should consider introducing a 'landlord' model of public ownership and private concessions. To ensure that infrastructure serves the wider public interest, these models should include requirements for multisectoral usage and rural–urban market connectivity. They should establish emergency response procedures for high-impact disruptions, during which strategic decision-making on usage and cargo prioritization would be temporarily transferred back to the government. A multi-decade timeline may be needed to ensure that long-term resilience needs are balanced against cost effectiveness and shorter-term returns.

Strategic investment partnerships between exporting countries and key trading partners could help to support infrastructure expansion and modernization, and contain maintenance costs

Strategic investment partnerships between exporting countries and key trading partners with the requisite financial capacity could help to support infrastructure expansion and modernization, and contain maintenance costs. Food-deficit countries such as the GCC member states and Singapore, for example, are already investing in agricultural production and export facilities overseas, but are currently focusing their efforts on relatively high-risk regions. An informal partnership between these states and major producers such as the US or Brazil would provide additional security of supply for importing countries, while supporting much-needed investment in infrastructure resilience in the producer countries.

Continued investment in agricultural extension services, research and development, and the cultivation and scaling up of alternative crops is needed to support a diversified grain production base (particularly in grains with a relatively high tolerance to climate stresses). International financial institutions and donor governments should offer financial incentives to businesses interested in investing in inland infrastructure in high-risk regions or marginal crops, particularly across the Black Sea producers and emerging producers in South America, sub-Saharan Africa and Southeast Asia.

6.2.3 Enhance confidence and predictability in global trade

A process to continually reduce the scope for export restrictions under the World Trade Organization (WTO) should be explored. The ability of governments to impose trade restrictions unilaterally and without warning increases the risk of contagious protectionism, as happened in 2008. Ideally, there would be an outright ban on export restrictions. Less ambitiously, WTO provisions relating to agricultural export restrictions could be clarified and strengthened in order to reduce the scope for ad hoc measures. In practice, making even small steps in the WTO in this area will be extremely challenging.

Reform of trade-distorting farm support in developed crop-exporting countries remains a priority. Current levels of support promote production of mega-crops at the expense of diversifying calorie production. In the context of climate

[324] Ramdoo, I. (2015), *Synergising and Optimising Mineral Infrastructure in Regional Development Strategies*, International Centre for Trade and Sustainable Development, http://e15initiative.org/wp-content/uploads/2015/09/E15-Extractive-Industries-Ramdoo2-FINAL-1.pdf (accessed 28 Apr. 2017).

change, a better use of public funds would be to support investment in overseas producers where crops other than maize, wheat, rice and soybean are grown, and/or in countries where agricultural expansion and intensification are possible but where food insecurity persists. Instead of subsidizing domestic farming, developed countries should prioritize investment in production, storage and transport capacity in sub-Saharan Africa, where cereal demand growth is expected to triple by 2050 but where yield gaps remain, supply chain losses are high and market integration is low.[325]

6.2.4 Develop emergency supply-sharing arrangements and smarter strategic storage

The FAO, WFP or AMIS should establish an emergency response mechanism among major players in the global food trade, modelled in part on that of the International Energy Agency in oil markets. Under such a mechanism, major strategic stockholding countries could establish data-sharing arrangements and agree rules for coordination during acute market disruptions. These arrangements and rules would govern, for example, the release and sharing of stocks and measures to relieve demand, such as the relaxation of biofuel mandates. This club of countries could undertake regular exercises to explore how they would coordinate in different worst-case scenarios.

Collaborative storage arrangements could be pursued along at-risk maritime trade routes, such as the 'critical food security corridors' that we propose might be designated by the UN. For example, security of supply between the Black Sea and MENA regions could be enhanced by exporting countries entering into extra-territorial storage agreements with Arab importers, so that a certain amount of Black Sea grain was stored in the MENA region. Such agreements would need to cover emergency access rights and pricing arrangements.

Governments should coordinate storage and agree emergency sharing provisions at regional level to reduce collective vulnerability. Strategic stocks should be secure but accessible to vulnerable population centres; a diversity of locations would reduce the risk of chokepoint disruptions impairing the ability of governments to build up or draw down stocks. Existing frameworks for transnational cooperation on infrastructure development and existing regional grain trade networks provide ample scope for the agreement of regional storage strategies.

Higher stock levels are needed to provide increased assurance against interruptions of supply in vulnerable countries. This is particularly urgent in countries in the Horn of Africa and the Middle East that rely on one or several critical or at-risk chokepoints. Where government capacity and competency to manage stocks efficiently are limited, public–private partnerships should be pursued in which stockholding at target levels is outsourced to the private sector. Adapting arrangements in the petroleum sector, it may be possible for governments in

[325] van Ittersum, M. K., van Bussel, L. G. J., Wolf, J., Grassini, P., van Wart, J., Guilpart, N., Claessens, L., de Groot, H., Wiebe, K., Mason-D'Croz, D., Yang, H., Boogaard, H., van Oort, P. A. J., van Loon, M. P., Saito, K., Adimo, O., Adjei-Nsiah, S., Agali, A., Bala, A., Chikowo, R., Kaizzi, K., Kouressy, M., Makoi, J. H. J. R., Ouattara, K., Tesfaye, K. and Cassman, K. G. (2016), 'Can sub-Saharan Africa feed itself?', *PNAS*, 113(52): 14964–14969, doi: 10.1073/pnas.1610359113 (accessed 26 Apr. 2017); Brenton, P., Portugal-Perez, A. and Regolo, J. (2016), *Food Prices, Road Infrastructure, and Market Integration in Central and Eastern Africa*, World Bank Policy Research Working Paper No. 7003, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2480196 (accessed 26 Apr. 2017).

vulnerable countries to lease silos to the private sector, while reserving priority access rights in the event of a supply shortfall. Agreements would need to cover minimum stock levels, the conditions under which normal commercial operations are ceased, and the terms under which stocks are transferred to the host government.

6.2.5 Build the evidence base around chokepoint risk

Strengthening the evidence base around the importance of trade chokepoints to food security, and enhancing understanding of the nature and severity of disruptive hazards, remain key first steps in the translation of chokepoint analysis into policy. Greater transparency and information-sharing around infrastructural resilience and capacity, risk exposure and risk management will also be important for the identification of vulnerability hotspots.

Data on real-time food trade would provide a powerful means of assessing risks to food supply chains, both for staple crops and fertilizers and for food and non-food commodities more broadly. Such a system would need to connect data on individual food shipments with assumptions about routes (for example, generated from AIS data). The data system could also be connected to existing transport network models able to explore rerouting options in the case of a major disruption to port infrastructure,[326] in turn facilitating scenario development and crisis simulation exercises.

The scope of AMIS's monitoring should be broadened to cover systemic chokepoints. It should include assessment of potential disruption risks, and data on performance such as throughput and congestion. Currently AMIS supports market stability by monitoring leading indicators of price volatility – providing an early-warning function – and increasing transparency of market data. Broadening its role to include appraisal and monitoring of the systemic importance of global food chokepoints, along the lines of the US Energy Information Administration's analysis of oil trade chokepoints,[327] would help to raise awareness of chokepoint-related risks.

Ongoing monitoring is needed to plan for congestion and failures, and identify investment priorities. A number of agencies – for example, the OECD's International Transport Forum (ITF) – are already tracking investments in infrastructure. Others, including the World Bank and World Economic Forum, are undertaking comparative infrastructure assessments. These agencies could widen their remit to include the collation and analysis of national-level data on infrastructure capacity, usage, maintenance and hazard exposure.

Harmonization of nationally reported, macro-level transport infrastructure and asset data, and tracking of spending and performance in the sector (as recommended by the ITF itself in a 2013 report),[328] would further boost the value and usability of monitoring. As it may be difficult to persuade national governments to disclose such

[326] For example, Martagan, T. G., Eksiouglu, B., Eksiouglu, S. D. and Grenwood, A. G. (2010), 'A Simulation Model of Port Operations during Crisis Conditions', *IEEE Xplore*, doi: 10.1109/WSC.2009.5429245 (accessed 20 Apr. 2017).
[327] US Energy Information Administration (2014), 'World oil transit chokepoints', https://www.eia.gov/beta/international/regions-topics.cfm?RegionTopicID=WOTC (accessed 2 May 2017).
[328] OECD/ITF (2013), *Understanding the Value of Transport Infrastructure: Guidelines for macro-level measurement of spending and assets,* International Transport Forum, Task Force on Measuring Transport Infrastructure Spending and Assets, https://www.itf-oecd.org/sites/default/files/docs/13value.pdf (accessed 28 Apr. 2017).

information, the reporting framework would need to be designed and managed in such a way as to inform and attract multilateral and private-sector financiers.[329] AMIS offers a strong institutional foundation upon which to promote data-sharing of this kind.

Industry-led dialogues could help bridge the gap between climate impact modelling and infrastructure resilience planning. Although climate impact models are increasingly sophisticated, it is often difficult to provide information at the level of resolution required for infrastructure planning. Dialogues between, on the one hand, pioneering companies and infrastructure industry associations – such as the World Association for Waterborne Transport Infrastructure (PIANC) – and, on the other, climate model 'downscaling' initiatives – for example, the Coordinated Regional Climate Downscaling Experiment (CORDEX) – could help to bridge this gap. These dialogues could enhance communications around the needs and constraints of infrastructure operators and developers, and respond to advances in the climate modelling community. Non-governmental groups engaged in climate-resilient development could also be involved.

Research councils and other funders should establish multidisciplinary research frameworks. These would seek to encourage researchers in the fields of food security, transport networks, disaster resilience, infrastructure development and governance, risk assessment and climate science to address key knowledge gaps, most urgently in at-risk food-importing regions and climate-exposed food supply hubs such as the Black Sea, South Asia and Southeast Asia. Additional research is needed into the dynamics of trade and the likely impacts of a chokepoint disruption in relation to dry bulk freight, as the majority of existing analysis is focused on container freight.

6.3 Concluding remarks

Climate change will have a multiplying effect on security and political hazards affecting the infrastructural backbone of international trade

International trade underpins global food security. Trade has facilitated specialization, reducing food prices and maximizing productivity, and producers have invested in response to market signals, raising output so that agriculture has kept pace with demand. Despite an explosion in global population, access to food has improved around the world.

The food system is nevertheless coming under increasing strain. While market forces have largely adjusted adequately until now, the capacity of international trade to correct for supply disruptions in a climate-changed world is less certain. Climate change will suppress growth in crop yields and make harvests more variable. It will threaten the reliability and integrity of the infrastructure on which international trade depends. In addition to more regular and more severe weather-induced damage to roads, railways, ports and inland waterways, climate change will have a multiplying effect on security and political hazards affecting the infrastructural backbone of international trade.

By virtue of their geopolitical importance and often climate-vulnerable locations, the global food trade chokepoints discussed in this report are likely vectors – and potential epicentres – of systemic disruption. In an increasingly unpredictable world, ensuring

[329] Ibid.

the resilience of populations and critical infrastructure to compound and cascading supply chain disruptions, and to 'black swan' events, will become increasingly vital yet ever more challenging. Without significant investment in new approaches to risk assessment and management, in infrastructural resilience and capacity, in strong governance and cooperation, and in the diversification of supply sources and routes, food trade chokepoints will pose a material and growing risk to systemic stability and to human security, chiefly in the world's most food-insecure and politically volatile regions.

Annex 1: Methodologies

A1.1 Chatham House Maritime Analysis Tool (CH-MAT)

The Chatham House Maritime Analysis Tool (CH-MAT) is a first-of-its-kind (Excel-based) data-analysis tool for assessing the importance of maritime chokepoints to global food trade.[330] The CH-MAT couples Chatham House's Resource Trade Database (CHRTD, see Section A1.2 below) with a set of detailed assumptions on the most likely routes taken by food-carrying dry bulk vessels between any two regions. Here we outline the key steps in our approach to the CH-MAT, and discuss some of its limitations and ways in which these may be addressed.

Key steps

Underpinning the CH-MAT is a set of assumptions relating to the maritime routes via which food shipments are transported from one region to another. We applied these assumptions to bilateral trade data from the CHRTD in order to estimate both the weight and value of staple grains – wheat, maize, rice and soybean – and fertilizers passing through a given chokepoint each year.

Step 1: Maritime chokepoint identification

The first step in our approach was to identify those maritime chokepoints that are of strategic global importance. The basis of this initial assessment was existing analysis of international trade along sea lines of communication, both for general freight and for grain shipments specifically. An extensive literature review was undertaken, spanning transport network analysis and maritime logistics reports,[331] Automatic Identification System (AIS)-driven mapping of maritime trade activity,[332] and energy supply risk analysis.[333]

From this literature review, we identified eight global maritime chokepoints that lie along the major east–west trade channels: the Panama Canal, Dover Strait, Strait of Gibraltar, Turkish Straits, Suez Canal, Strait of Bab al-Mandab, Strait of Hormuz and Strait of Malacca. This grouping differs slightly from the list of global oil chokepoints drawn up by the US Energy Information Administration (EIA): we do not include the Danish Straits or Cape of Good Hope (while the EIA does not include the Dover Strait or Strait of Gibraltar). The reasons for this are as follows:

[330] The CH-MAT was developed by Laura Wellesley and Felix Preston.
[331] For example, Rodrigue, Comtois and Slack, B. (2017), *The Geography of Transport Systems*; Kaluza, P., Kölzsch, A., Gastner, M. T. and Blasius, B. (2010), 'The complex network of global cargo ship movements', *Journal of the Royal Society Interface,* doi: 10.1098/rsif.2009.0495 (accessed 8 Jun. 2017); UNCTAD (2016), *Review of Maritime Transport 2016*, New York and Geneva: UNCTAD, http://unctad.org/en/PublicationsLibrary/rmt2016_en.pdf (accessed 8 Jun. 2017).
[332] For example, the UCL Energy Institute's www.shipmap.org.
[333] For example, Emmerson and Stevens (2012), *Maritime Choke Points and the Global Energy System*; Mitchell (2014), *Asia's Oil Supply: Risks and Pragmatic Remedies*; Komiss, W. and Huntzinger, L. (2011), *The Economic Implications of Disruptions to Maritime Oil Chokepoints*, CNA, https://www.cna.org/cna_files/pdf/D0024669.A1.pdf (accessed 8 Jun. 2017); Nincic (2002), 'Sea Lane Security and U.S. Maritime Trade: Chokepoints as Scarce Resources'.

- The Danish Straits are an important channel for trade to and from the Baltic states, and to and from Russia via the Gulf of Finland. For grain and fertilizer, however, the majority of the Baltic states' trade is with mainland Europe and is transported overland. While Russia's export capacity on its Baltic coast is expanding, the vast majority of its grain and fertilizer shipments continue to be handled at the Black Sea ports.
- While the Cape of Good Hope is undoubtedly a recognized 'chokepoint' in naval settings and in common parlance, it is not considered a chokepoint in the context of our analysis. Unlike the eight maritime chokepoints identified above, the cape is neither a narrow strait nor a man-made canal; thus, while passage may be impeded by poor weather or other hazards, the nature of this impediment will differ fundamentally from the complete blockages possible through straits or canals.

The Danish Straits and Cape of Good Hope are nevertheless included in the overall CH-MAT database for added clarity in routing assignments. So too are Cape Horn, the Northern Sea Route, the South China Sea and the East China Sea (see Figure 26).

Figure 26: Chokepoints used in the elaboration of Chatham House Maritime Analysis Tool

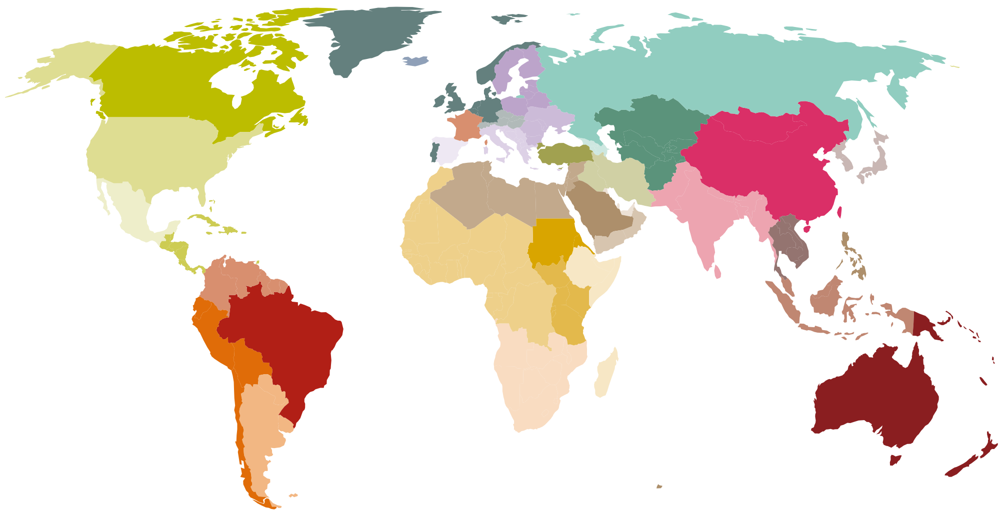
Step 2: Regional groupings

Next, each country was assigned to a regional grouping based on the most likely maritime route via which it would trade (see Figure 27). This assignation gave rise to a set of country groupings to which common trading routes may be applied; this step allowed for the 10,884 bilateral grain trade flows in the CHRTD to be converted into a more manageable list of 42 region-to-region flows.

This step implies no trade-off in terms of granularity; bilateral flows can still be interrogated and estimated at the country level. And it brings considerable gains in terms of developing plausible routes; standard regional breakdowns have little relevance to the consideration of convenient coastal access routes.

For the most part, the 42 regions identified comprise multiple – up to 26 – countries. However, the CH-MAT also has seven single-country regions, such as Canada, Russia and the US.[334] Single-country regions are used for countries that have two or more major coastlines and enjoy access to multiple maritime routing options for imports and exports. Canada, for example, may export its agricultural goods from either its western or eastern coast, depending on whether the shipments in question are destined for Asian or European markets. Similarly, Russian fertilizers may be shipped from the country's ports on the Baltic Sea, the Black Sea or the Sea of Japan; were Russia simply grouped with other exporting countries in Eastern Europe – Belarus or Ukraine, for example – important trading differences would be overlooked.

Figure 27: Regional groupings used in Chatham House Maritime Analysis Tool



Source: Authors' own analysis.

Step 3: Trade routes and chokepoint assumptions

The third step involves assigning each region-to-region flow to one or several assumed maritime trading routes. In light of the focus of our research, maritime chokepoints are used as a proxy for trading routes; queries can be run in the CH-MAT on the basis of trade transiting the Panama Canal specifically, for example, but not on the basis of trade travelling westbound or eastbound via unspecified routes between the Atlantic and Pacific oceans.

Our routing assumptions are based primarily on distance and shipping time. Where two or more routing options are available (for example, trade between Western Europe and East Africa may be shipped via the Suez Canal, or via the South Atlantic and under the Cape of Good Hope), a decision is made on whether to assign the totality of the region-to-region flow to one route or to split it between two. In those cases where the difference in shipping time between two routes is three days or greater, the shortest route is preferred; where two routing options are of comparable

[334] The full list of single-country regions is as follows: Brazil, Canada, Mexico, Russia, Saudi Arabia, Turkey and the US.

distance – with a difference in shipping time of less than three days – the region-to-region flow is split equally between both routes. The distance between region *x* and region *y* is calculated using the online searates.com tool.

Where possible, additional data and anecdotal evidence are used to sense-check and fine-tune routing assumptions. In those regions that span an extensive seaboard and include multiple countries – and those regions that include more than one seaboard – we use available port throughput data and existing analysis of principal grain trade hubs to pinpoint likely entry and exit points for the region as a whole. By way of example, ports at the southern end of our Western Africa region are the most important for trade in cereals within that region, and so we use these ports as the basis for all trade route assumptions to and from the Western Africa region. In the case of Mexico, national port throughput data indicate that both the east and west coasts have important grain-handling terminals, though the eastern terminals have roughly five times' the capacity of those on the west coast. We therefore assume that 15 per cent of cereals imports enter the country from the Pacific and 85 per cent via the Gulf of Mexico.

For certain regions, more than one grain trade hub is identified. In these cases, we apply sub-regional routing divisions and apply these consistently, irrespective of the origin or destination of trade. This consistency maximizes the replicability of our approach and ensures that our assumptions are based as far as possible on the actual capacity of alternative port areas. This is the case for Russia, which, as noted above, has three possible export and import routes: via the Baltic Sea or Black Sea in the west of Russia, or via the Sea of Japan in the east. Relatively detailed port capacity data for Russia, made available by the US Department of Agriculture (USDA), provide a basis on which to apportion grain imports and exports between the three areas. These data, together with anecdotal evidence from other sources, indicate that the far eastern trade terminals – in and around Vladivostok – are expanding but not yet handling significant volumes of grain shipments (in part because the country's wheat production is centred in Russia's western and southern regions). The Baltic ports handle a reasonable share of grain shipments, but the Black Sea ports provide the primary access point for international markets. We therefore route 90 per cent of Russia's agricultural exports and imports via the Black Sea, in line with port throughput and capacity data, and do so consistently for all region-to-region flows.

Common routing assumptions are applied to all four grains in all regions except the US. The US is unique both in the granularity of its port throughput data and in the marked differences between export patterns for wheat, maize and soybean. Grain export data are broken down both by grain and by port region, allowing us a degree of nuance not possible in other regions. On the basis of these data, we divide the US into three major sub-regions (the Gulf Coast, Pacific northwest coast and east coast), and apply different assumptions for each crop type (see Table 8).

Table 8: Share of US exports for staple crops shipped from major US port areas

Port area	Soybean and rice	Wheat	Maize
Pacific northwest coast	25%	47%	17%
Gulf Coast	59%	40%	67%
East coast	7%	7%	2%
Other	9%	6%	13%

Source: Authors' analysis based on USDA (2015), *Grain Transportation Report – February 12*, https://www.ams.usda.gov/services/transportation-analysis/gtr/archive-2015 (accessed 25 Jan. 2017).

Each region-to-region routing assumption is stored within a two-dimensional array of 1,766 rows (representing every possible region-to-region flow in the database), and 14 fields (representing the eight maritime chokepoints deemed of global strategic importance, plus the Danish Straits, Cape of Good Hope, Cape Horn, Northern Sea Route, South China Sea and East China Sea). Trade flows attributed to 'areas not elsewhere specified' in the CHRTD are not assigned a routing assumption in our model.

Methodological limitations

As the first tool of its kind, the CH-MAT includes a number of assumptions and limitations which warrant further probing if the tool's accuracy and robustness are to be strengthened. Below, we briefly outline these and identify priorities for future research.

Assumptions

On the basis of an extensive literature review and a series of conversations with maritime industry experts, we make the assumption that all grain trade is transported by dry bulk vessels. This is because, while the use of containers in the transport of grain is increasing, available evidence suggests that containerized shipments as a share of total shipments remain low.[335] Our routing assumptions therefore imply single point-to-point voyages. If liner routes were also considered, our approach to region-to-region routing assumptions (based on the distance and shipping time between major trade hubs in region *x* and region *y*) might no longer be valid; liner vessels would likely call at other ports en route – picking up or dropping off grain shipments from other trading partners – rather than steaming directly from region *x* to region *y*.

Furthermore, the CH-MAT does not account for the movement of vessels empty of cargo. This is because the underlying data for the CH-MAT consist of bilateral trade data rather than port throughput data. Taking only cargo-carrying vessels into account makes sense when assessing the strategic importance of certain routes to food security; in the case of a major blockage to the Panama Canal, for instance, vessels carrying grain shipments, not those that are empty, will be of concern to the food security community. But as empty vessels can also be used in identifying potential points of congestion, their omission from our analysis may lead to an underestimate of usage levels at certain chokepoints or along certain trade routes.

[335] Munro (2011), 'Containers Move High-Value Exports – When do Containers Work Best For the Grain Buyer and the Grower?'; Lirn and Wang (2016), 'The Determinants of Containerised Grain Shipping' (accessed 8 Jun. 2017).

We apply to fertilizer flows the same set of routing assumptions as those developed for grain flows. Having consulted available data on fertilizer shipments to and from major consumers and producers, we are confident that this approach is valid. However, further analysis of the specific patterns of fertilizer trade and of specialized fertilizer-handling terminals would be needed to be sure that no important differences between fertilizer and grain trading patterns have been missed.

Where both maritime and overland trade routes exist between region *x* and region *y* and are of comparable distance, we assume that the maritime route will be taken. The exceptions are where seaborne shipments would imply a significant detour: for example, in the case of trade between landlocked countries in Central Asia.

Limitations

In developing our approach to the CH-MAT, we faced a number of challenges arising from poor data availability. Very little analysis has been undertaken of the seaborne movement of grain and/or fertilizer; and while there exists a relatively rich body of literature on global transport networks and patterns of international maritime trade, the idiosyncrasies of shipping data are such that commodity-specific analysis is extremely difficult.

AIS data distinguish between vessel types, for example, but do not detail the cargo carried by any given vessel. Apps such as MarineTraffic allow users to follow the movement of a particular dry bulk carrier but do not indicate the nature of the dry bulk cargo on board; as such, it is not possible to distinguish between coal shipments and wheat shipments, for example. And while rudimentary data – the vessel type and forecast route, for example – are open-access, further details such as the previous and next ports of call are behind a pay wall and therefore likely to be unavailable to many civil society and public actors.

The quality and availability of national data on port capacity, export flows and import flows are extremely variable. Some countries (such as the US and Saudi Arabia) collect and make public fine-grained data on port capacity and throughput, sometimes broken down by commodity type. Others differentiate only between container shipments and dry bulk shipments. Turkey, for example, reports on dry bulk throughput at its ports, but does not distinguish between grain and other dry bulk such as coal and sand. Other countries (such as the Pacific Island states) have little or no open-access data on import and export shipments, let alone statistics for individual port areas.

Consistency in port throughput data across countries is further limited by discrepancies in reporting. While certain countries report in weight-in-tonnage, others report in value-in-currency; and, while certain countries are consistent in their annual reporting, others provide data on an ad hoc basis. We apply consistent rules when selecting data for use in the CH-MAT – data in weight are preferred over data in value wherever possible; the most recent data available in the period 2010–16 are always used – but discrepancies certainly remain.

Finally, the use of bilateral trade data itself implies certain limitations in analysing the patterns of trade in grain. Trade data are reported only annually, and as such the CH-MAT estimates aggregate chokepoint throughput volumes on a yearly basis. This masks important seasonal fluctuations in the export and import of grain; peak flows from South America during the soybean harvest season are balanced out by yearly lows earlier in the cropping cycle, for instance. While a valuable indication of port areas of systemic interest, the CH-MAT therefore offers little basis for capturing periods of relatively high risk when a major disruption to Brazil's southern ports could, for example, have a disproportionately large impact on global soybean supply.

Review

A number of maritime industry experts and food security analysts provided valuable feedback on our approach to the project since its inception in early 2015. In the summer of 2016, we undertook a more formal process of peer review through which we presented the key steps, assumptions and limitations of the CH-MAT. The reviewers were Dr Tristan Smith (University College London Energy Institute), Dr Michael Traut (University of Manchester Tyndall Centre) and Dr Conor Walsh (University of Manchester Tyndall Centre). We are extremely grateful to these reviewers for their feedback and guidance. However, we remain solely responsible for the development of the CH-MAT and for any errors it may contain. We welcome feedback on how this important tool may be improved and expanded in the future.

A1.2 Chatham House Resource Trade Database (CHRTD)

Richard King, Felix Preston and Siân Bradley

The Chatham House Resource Trade Database (CHRTD) is a repository of statistics on bilateral trade in natural resources between more than 200 countries and territories.[336] The database includes the monetary values and masses of trade in over 1,350 different types of natural resources and resource products, including agricultural, fishery and forestry products, fossil fuels, metals and other minerals, and pearls and gemstones. It contains raw materials, intermediate products and by-products.

Dealing with complexity

Bilateral statistics are critical to understanding global resource trade, but existing data are often difficult to access and use. The original data source for the CHRTD is the International Merchandise Trade Statistics (IMTS). IMTS data are collected by national customs authorities and compiled into the United Nations Commodity Trade Statistics Database (UN Comtrade)[337] by the United Nations Statistics Division. UN Comtrade utilizes three distinct trade classification systems: the Harmonized Commodity Description and Coding System (HS), the Standard International Trade Classification (SITC), and Broad Economic Categories (BEC). Of these, the CHRTD employs the HS taxonomy (1996 revision), which assigns HS codes to all forms of traded goods in a hierarchical structure (two-, four- and six-digit codes respectively represent commodity chapters, headings and subheadings).

[336] The CHRTD was developed by Jaakko Kooroshy. The development of 'resourcetrade.earth' was led by Felix Preston, Richard King and Siân Bradley.
[337] UN Comtrade, http://comtrade.un.org/.

Across the resource landscape alternative repositories of trade data are available, but these do not offer the breadth and depth of analysis that UN Comtrade permits. For example:

- Data from the United Nations Conference on Trade and Development (UNCTAD)[338] have the greatest temporal availability, with some aggregate categories dating back to 1948, but even recent series lack commodity-level (six-digit HS code) detail.
- The FAO[339] provides comprehensive bilateral trade data for agriculture, forestry, fisheries and aquaculture, but not for other resource domains. Much of the available data share the same origins as UN Comtrade data and are not necessarily more accurate.
- The USDA Global Agricultural Trade System (GATS)[340] is similarly domain-constrained and focuses on US trading partners. Similarly, the European Commission's EUROIND database[341] covers only trade with and between EU countries.
- The IEA[342] provides comprehensive energy balance and energy flow statistics, but trade statistics are limited to gas flows within and to Europe.
- US EIA data[343] include national energy consumption, production, and import and export statistics, but lack bilateral detail.
- The world oil and gas databases developed by the Joint Organisations Data Initiative (JODI-Oil[344] and JODI-Gas[345]) were developed as transparency tools rather than trade databases. Unlike other databases, JODI does not adjust reported figures or substitute missing figures, so coverage is incomplete.
- Commercial sources such as the *BP Statistical Review of World Energy*[346] provide comprehensive energy trade data, but no bilateral dimension.

UN Comtrade is therefore arguably the most comprehensive source of merchandise trade statistics available; volumetric and monetary value data are catalogued under more than 5,000 HS codes, and the monetary values of trades are available as far back as 1962. However, it does present several challenges for users focusing on resource trade, which the CHRTD and Chatham House's resourcetrade.earth site address:

- The HS system is not easy to use. Its nomenclature has evolved historically as a pragmatic and comprehensive industrial taxonomy for the broad range of internationally traded goods.

[338] UNCTAD Stat, http://unctadstat.unctad.org/EN/.
[339] UN FAOSTAT, http://www.fao.org/faostat/en/#data/TM.
[340] USDA Foreign Agricultural Service, Global Agricultural Trade System (GATS), https://apps.fas.usda.gov/gats/.
[341] EUROSTAT, http://ec.europa.eu/eurostat/web/euro-indicators/international-trade/euro-indicators-database.
[342] IEA Statistics, https://www.iea.org/statistics/.
[343] EIA International, https://www.eia.gov/beta/international/.
[344] JODI Oil World Database, http://www.jodidata.org/oil/.
[345] JODI Gas World Database, http://www.jodidata.org/gas/.
[346] *BP Statistical Review of World Energy*, http://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html.

- The scale hinders simple queries: with over 3 billion trade records since 1962,[347] finding the right data is not always easy and the size of data queries can be difficult to manage.

The IMTS data are of variable quality: missing data, trade mispricing, unreported and illegal trade, and general mistakes and inconsistencies all cast doubt over the reliability of certain reported trade flows.

The presence of between one and four data points for every trade flow complicates use: both exporters and importers are expected to report trade values and trade masses. If these records are incomplete or do not correspond with one another, there may be uncertainties about the reliability of data and/or about which reporter is the most authoritative.

Introducing clarity

The CHRTD reorganizes data around natural resources. As the IMTS and HS systems contain all types of traded goods – including manufactured goods – analysing natural resource trade flows in UN Comtrade typically requires amalgamating a variety of HS codes. The difficulty of this varies: products that have a long history of being traded extensively are captured in greater detail than those that are traded less frequently. For example, there is a single HS code associated with rare-earth elements, but several hundred codes assigned to steel and steel products. The CHRTD overcomes this problem by selecting over 1,350 HS codes that are identifiable as raw materials or relatively undifferentiated intermediate products, and by grouping them by resource type. For example, copper ores and concentrates, and intermediate copper products such as mattes, bars, wires and scrap are all classified into a single 'copper' category, enabling global copper trade to be tracked at different stages of the value chain. The CHTRD employs a five-tier resource taxonomy permitting queries to be as atomized or aggregated as required.

The CHRTD employs a systematic approach to identify and manage data gaps and errors. The CHRTD is subject to the same data gaps and weaknesses as are apparent in other sources of international merchandise trade data.[348] However, it exploits the maximum information available within UN Comtrade to assess the reliability of individual trade records, and to present as complete and reliable a picture as possible. The approach taken relies on two assumptions. First, for each trade flow the values (in US$) and masses (in kg) reported by the exporter and importer should approximate to one another. The reported monetary values are unlikely to be exactly the same, since exports are typically reported on a 'free on board' (fob) basis, whereas imports are typically reported on a 'cost, insurance and freight' (cif) basis. Second, we expect the reported prices per tonne to relate to world market prices. Unlike

[347] UN Trade Statistics (undated), 'What is UN Comtrade?', https://unstats.un.org/unsd/tradekb/Knowledgebase/50075/What-is-UN-Comtrade.
[348] For a full discussion of reporting asymmetries, see Markhonko, V. (2014), 'Asymmetries in official international trade statistics and analysis of globalization', discussion paper, International Conference on the Measurement of International Trade and Economic Globalization, Aguascalientes, Mexico, 29 September–1 October 2014, https://unstats.un.org/unsd/trade/events/2014/mexico/Asymmetries%20in%20official%20ITS%20and%20analysis%20of%20globalization%20-%20V%20Markhonko%20-%2018%20Sep%202014.pdf (accessed 8 Jun. 2017).

in some alternative approaches to reconciling importer and exporter reports, we make no assumptions about the general reliability of country reporting across multiple commodities or years; each individual report is assessed on its own merit.

Logical operations are used to produce a transparent decision on the relative reliability of each data point and to reconcile the importer and exporter reports into a single record. Each record incorporates the value and mass of trade in the given commodity between the two countries in the given year. In each case we consider the degree of similarity between the importer and exporter reports. In cases where either trade partner reports the monetary value and the mass of the trade (some reports contain only the value), the reported price per tonne is assessed relative to the global distribution of unit prices for the same commodity in the same year. If both partners report a non-outlying unit price, then a weighted average of the two reports is recorded; the weighting factor is calculated according to the relative divergence of each unit price from world average market prices. Data points that are deemed unreliable and irreconcilable are labelled as such and quarantined. A manual review of some of the larger flows that have been excluded from the database by this process allows us to reintroduce important flows at the global level, using external sources where necessary.

A full specification of this methodology will be made available at a later date.

A1.3 Chatham House Food Security Dashboard (CH-FSD)

The Chatham House Food Security Dashboard (CH-FSD) provides a framework with which to combine existing measures of food insecurity with a new understanding of chokepoint risk. It assesses the chokepoint risk of 205 countries in terms of their exposure (at national level) and vulnerability (at national level and at household level) to chokepoint disruption. The 18 indicators are shown in Table 9.

Table 9: Indicators and sources used in Chatham House Food Security Dashboard

Domain	Indicator	Data source
Trade dependence	Cereal import dependency ratio (%)	FAO
Chokepoint reliance	Aggregate maize, wheat, rice and soybean imports passing through at least one maritime chokepoint (% by weight)	CH-MAT
	Aggregate maize, wheat, rice and soybean imports passing through a critical maritime chokepoint (% by weight)	CH-MAT
Food insecurity	Household income spent on in-home food consumption (%)	World Bank
	Prevalence of undernourishment (%)	FAO
Food availability	Aggregate stock-to-use ratio for maize, wheat, rice and soybean (%)	USDA
	Average dietary energy supply adequacy (%)	FAO
State fragility	Fragile state? (Y/N)	OECD
	Political stability and absence of violence/terrorism. Composite indicator (approx. -2.5 to 2.5, mean=0, higher values correspond to better governance)	World Bank
Infrastructure quality	Existence of adequate crop storage facilities? (Y/N)	EIU
	Road infrastructure quality (1–7, 1=worst, 7=best)	World Economic Forum
	Rail infrastructure quality (1–7, 1=worst, 7=best)	World Economic Forum
	Port infrastructure quality (1–7, 1=worst, 7=best)	World Economic Forum
Climate vulnerability	People killed/affected by floods, storms, droughts (per 100,000 people – worst year and annual average, 2005–14)	EM-DAT
	Total economic damage caused by floods, storms, droughts (% of GDP – worst year and annual average, 2005–14)	EM-DAT
Social protection	Social protection coverage for poorest quintile (%)	World Bank
Macroeconomic vulnerability	Cash surplus/deficit (% of GDP)	World Bank
	Value of food imports in total merchandise exports (%)	FAO

Data sources as follows: Centre for Research on the Epidemiology of Disasters (CRED) (undated), 'EM-DAT: The International Disaster Database', http://emdat.be (accessed 15 Jun. 2017); Chatham House Maritime Analysis Tool; Chatham House (2017), 'resourcetrade.earth' (2015 data); Economist Intelligence Unit (2016), 'Global Food Security Index', http://foodsecurityindex.eiu.com (accessed 3 Jun. 2017); FAO (2016), 'Food security indicators', http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.WTRQthiZOHp (accessed 22 Mar. 2017); OECD (2015), *States of Fragility 2015: Meeting Post-2015 Ambitions*, Paris: OECD Publishing, doi: 10.1787/9789264227699-en (accessed 5 Jun. 2017); Schwab, K. (ed.) (2015), *The Global Competitiveness Report 2015–2016*, Geneva: World Economic Forum, http://www3.weforum.org/docs/gcr/2015-2016/Global_Competitiveness_Report_2015-2016.pdf (accessed 9 May 2017); USDA Foreign Agricultural Service (2017), 'Production, Supply and Distribution', https://apps.fas.usda.gov/psdonline/app/index.html#/app/advQuery (accessed 3 Jun. 2017); World Bank (undated), 'ASPIRE Indicators at a glance', http://datatopics.worldbank.org/aspire/indicator_glance (accessed 3 Jun. 2017); World Bank (2011), 'International Comparison Program', http://siteresources.worldbank.org/ICPEXT/Resources/ICP_2011.html (accessed 3 Jun. 2017); World Bank (2015), 'Worldwide Governance Indicators', http://info.worldbank.org/governance/wgi/index.aspx#home (accessed 3 Jun. 2017).

Intended purpose and limitations

The CH-FSD is intended to permit ready analysis and comparison of values within and across indicators, domains and countries. It permits interrogation of the relative and absolute levels of risk across traditional and non-traditional measures of food insecurity, and affords a greater appreciation of the varied interactions of different sources of exposure and vulnerability. We deliberately do not create one composite chokepoint risk indicator from the constituent parts because to do so would be reductionist – stripping out the complexities – and arbitrary, in terms of any decisions about how to weight components differentially. Although we believe this approach is justified, this does mean that the CH-FSD requires careful interpretation and an appreciation of which of the three data point values (see below) is most appropriate for any given interrogation. Additionally, the CH-FSD is constrained by data availability, and by data quality in the underlying indicators relied upon.

Approach

The indicators employed are selected to provide a broad measure of countries' exposure and vulnerabilities within the domains specified. Among the criteria for inclusion were ready comprehension, lack of overlap with other indicators (composite indices measuring vulnerability across several domains were deliberately excluded), and broad and contemporary country coverage. Nonetheless, indicators vary in terms of country coverage, scale and latest year of data availability. In all instances the most recently available data (at the time of writing) from secondary sources were used. However, the data publication years range from 2008 to 2013; as such, and without annual data for each indicator, the CH-FSD reflects a snapshot based on the best available data, rather than an annual measure that can be compared year on year.

As the various source data series measure disparate phenomena, and are constructed on different scales, a process is required to standardize them for comparison. First, a 90 per cent winsorization is performed to reduce the influence of outliers on the data series. A 90 per cent winsorization sets the bottom 5 per cent of values to the value of the fifth percentile, and sets the top 5 per cent of values to the value of the 95th percentile. Thus countries that are outliers in a data series are not discarded from the dataset (unlike with trimming), but they are limited in their extremity.

Second, a standard minimum-maximum normalization is applied to the winsorized data. This rescales values from their original range and units to a comparable 0–100 scale. The minimum value present in the data is assigned a value of zero, the maximum value is set to 100, and all values in between are proportionally revalued. Min-max normalization captures the best and worst values present in the data, not the theoretical minimum and maximum values attainable. Where necessary, min-max normalized values are inverted so that no matter what the underlying data series, the maximum value (100) always represents the best score present in the data series and the minimum value (0) represents the worst score.

Third, the quartile of each value in the data series is recorded. This provides a rapid intuitive understanding of how any one data point compares with any other, and of how skewness is affecting the data. For example, if there is positive skew (i.e. the mean value is greater than the median), min-max normalized values may be relatively low but still appear in the top quartile. This suggests that although their performance is noticeably inferior to the top performers in the dataset, they still compare relatively well with the majority of the other countries. A high min-max value but a low quartile value suggests the presence of a large number of countries with high min-max values. Thus, the quartile values are most useful for rapidly and crudely considering how a score compares with all other scores in the series, whereas the min-max value gives a better sense of the score relative to the best and worse scores (once extreme outliers have been accounted for). In the full version of the CH-FSD, for each data point we record three values, with the utility of each value depending on the current level and purpose of analysis. These values are:

- the raw value in the native units for the series;
- the winsorized max-min values, displayed on a four-colour gradient, with each colour representing a quarter of the range 0–100; and
- the quartile of each normalized value, displayed on a four-colour gradient, with each colour representing a quartile.

Annex 2: Examples of Chokepoint Disruption

Below we provide examples of disruptions and transit delays that have occurred in major food trade chokepoints since 2002. These examples were used to inform Table 2 in Section 3.4, which indicates the relative risk of disruption or passage restriction at each of the 14 chokepoints featured in this report.

The list of disruptions is far from comprehensive; instead, it is intended to be an illustrative overview of the heterogeneity and frequency of small- or medium-scale disruptions at key trade chokepoints over a period of 15 years. Our analysis classifies chokepoint hazards into three categories – weather and climate risk; security and conflict risk; and political and institutional risk – and further divides these into subcategories, such as 'haze and fog', 'trade and transit controls' etc. (see Table 10). The illustrative list of disruptions (Table 11) assigns each historical example of disruption to one of these 11 subcategories.

We identified and compiled examples of disruption through a desk-based review of news reports and open-source literature from industry, academia and civil society; in the absence of an existing framework for the reporting of chokepoint disruptions, there was limited potential for a more methodical approach. We believe that a robust, systematic approach to documenting chokepoint disruptions and quantifying their impacts on food trade is urgently needed to support the effective assessment and management of chokepoint risk.

A maximum of three incidents are noted for each hazard category. Key search terms were in English; foreign-language material was not included. Examples of weather- and climate-induced disruptions and of politically and institutionally induced disruptions are limited to those with a reported impact on freight operations. Examples of conflict- and security-related incidents, on the other hand, include attempted attacks and events that had no reported impact on traffic. The authors understand these incidents to be qualitatively distinct from those relating to weather and political effects. Terrorist activity, breakouts of armed conflict and state-led attacks on vessels are considerably less likely to affect chokepoint transit in the short term, but have broader and longer-lasting implications for food trade and prices (e.g. as a deterrent to commercial or humanitarian shipments, or as a source of upward pressure on transport costs and food prices if war insurance premiums are raised).

Some further general caveats and specific points merit explanation:

- Scant and variable data on chokepoint disruptions limit the scope for a comprehensive review of events, both small- and large-scale. The majority of available information is anecdotal in nature, often reported by local news services or industry organizations and generally lacking much specific detail. The overview here should therefore be understood as indicative of the relative frequency of disturbances at each of the 14 chokepoints, and illustrative only of events significant enough to raise concern among mainstream media, agricultural traders or the transport industry.
- The severity of disruptions noted varies considerably, both in terms of the scale of damage/duration of transit disruption and in terms of the longer-lasting impact. Without an in-depth assessment of the first- and second-order impacts of these incidents, it is not possible to gather a full picture of the risk level at each

chokepoint. By differentiating between the nature of disruptive hazards, we can nevertheless get an idea of the differing risk profiles across the 14 chokepoints.

- If chokepoint risk is to be fully incorporated into risk assessment and management frameworks within the field of food security and beyond, a more systematic and robust approach is needed to compile available information on past disruptions. At national level, a coordinated process involving port and throughput data analysis, industry engagement and information-gathering among infrastructure operators would likely yield considerably more detailed and complete accounts of incidents affecting trade.

Table 10: Hazard categories

Hazard category	Hazard subcategory	Hazard code
Weather and climate risk	Temperature extremes	W-T
	Flood and drought	W-F/D
	Storms	W-S
	Haze and fog	W-H/F
Security and conflict risk	Conflict	S-C
	Terrorist attack	S-T
	Piracy*	–
	Cyberattack	S-C/A
Political and institutional risk	Trade and transit controls	P-T
	Disrepair	P-D
	Unforced delays	P-U

* Owing to the often high number of attempted or successful pirate attacks – small- or large-scale – individual incidents are not included in Table 11. Instead we note below those maritime chokepoints where many instances of piracy have been reported over the period 2002–17.

Piracy is a pervasive threat to trade through the Strait of Bab al-Mandab, the Strait of Malacca and, to a lesser extent, the Strait of Hormuz; countless instances of attempted and successful pirate attacks have been reported at each chokepoint over the period 2002–17. Details of the frequency and nature of these incidents are provided by the International Maritime Bureau (IMB)'s Piracy Reporting Centre.[349] The UN Office on Drugs and Crime also provides analysis of the incidence of piracy.[350]

[349] IMB Piracy Reporting Centre, https://www.icc-ccs.org/piracy-reporting-centre.
[350] UNODC Global Maritime Crime Programme, https://www.unodc.org/unodc/en/piracy/index.html?ref=menuside.

Table 11: Examples of chokepoint disruptions between 2002 and 2017

Chokepoint	Year of incident	Hazard code	Brief description	Source
Panama Canal	2010	W-F/D	Flooding prompts temporary closure of canal.	CNN[1]
	2015	W-F/D	Drought lowers water levels, and restrictions on transit are introduced.	*TIME*[2]
	2015	W-H/F	Periods of fog delay transit and contribute to vessel backlog.	Safety4Sea[3]
	2016	W-F/D	El Niño-induced drought sees water levels drop and prompts draught restrictions through canal.	IHS Fairplay[4]
	2017	P-D	'Unforeseen' repair work results in three-day closure of canal's east lane.	Protection Vessels International[5]
Dover Strait	2004	P-U	Fishermen blockade part of English Channel in protest over proposed fishing regulations.	BBC News[6]
	2008	P-U	Fishermen block key shipping lane in English Channel in protest over fuel prices.	Reuters[7]
	2015	P-U	Attempted crossings by migrants in Calais disrupt ferry and Eurotunnel traffic, causing a tailback of over 3,000 trucks along the major road approaching the Port of Dover.	Freight Trade Association[8]
	2016	W-S	Vessels crossing English Channel are delayed by high winds.	Press Association[9]
Turkish Straits	2013	W-S	Poor visibility during snowstorm prompts closure of Bosphorus Strait.	Reuters[10]
	2014	W-H/F	Heavy fog causes Bosphorus Strait and Dardanelles to close.	Maritime Connector[11]
	2015	W-S	Snowstorm causes closure of Bosphorus Strait.	Platts[12]
	2016	S-C	Attempted coup in Turkey halts transit of grain shipments through Bosphorus Strait.	Reuters[13]
	2017	W-S	Heavy snow halts shipping through Turkish Straits.	Reuters Africa[14]
	2017	W-H/F	Bosphorus Strait is closed due to poor visibility.	*Hellenic Shipping News*[15]
Suez Canal	2010	W-H/F	Heavy fog causes delay to transit.	*Egypt Independent*[16]
	2010	W-S	Severe storms disrupt shipping through canal.	US NOAA[17]
	2013	S-T	An attack is attempted on a container ship.	AFP[18]
	2015	W-S	Canal traffic halted owing to strong winds.	Al Arabiya[19]
	2015	S-T	Multiple bomb attacks attempted by Muslim Brotherhood.	*World Maritime News*[20]
	2015	W-S	Sandstorm prompts closure of canal.	*Israel National News*[21]
Strait of Bab al-Mandab	2015	S-C	All major ports in Yemen closed due to Saudi airstrikes.	*World Maritime News*[22]
	2016	S-T	Anti-shipping missiles are fired on UAE ship by Iranian-backed Houthi rebels.	Washington Institute[23]

Chokepoint	Year of incident	Hazard code	Brief description	Source
	2017	S-C	Multiple attacks on vessels transiting the strait.	Washington Institute[24]
Strait of Hormuz	2015	S-C	Iranian patrol boats fire shots at a cargo ship before boarding and seizing it.	Reuters[25]
Strait of Malacca	2015	W-H/F	Delays to traffic occur owing to poor visibility resulting from haze.	Al Jazeera[26]
US inland waterways and rail network	2005	W-S	Grain operations along Lower Mississippi disrupted for weeks owing to damage from Hurricane Katrina.	Envision Freight[27]
	2008	P-U	Congestion on railways and competition for capacity cause backlog of grain shipments in storage facilities.	CBS News[28]
	2010	W-S	Rail services severely interrupted owing to heavy snowstorm.	US NOAA[29]
	2011	W-T	High temperatures cause railway tracks to buckle, creating 'sun kinks' and resulting in derailments.	*Scientific American*[30]
	2012	W-S	Grain operations at mouth of Mississippi River temporarily shut down owing to high winds and rain brought by Hurricane Isaac.	Reuters[31]
	2012	W-T	Heatwave results in 'sun kinks' on railways, causing derailments and delays.	*Scientific American*[32]
	2012–13	W-F/D	Drought reduces water levels along Mississippi, severely restricting barge traffic.	*National Geographic*[33]
	2013	W-F/D	Barge traffic on Mississippi is subject to a temporary halt and prolonged delays due to flooding.	Reuters[34]
	2014	P-U	Rail delays hinder grain shipments and cause backlog in storage facilities.	*Wall Street Journal*[35]
	2016	W-F/D	Traffic on Mississippi is halted owing to flooding.	Reuters[36]
	2016	P-D	Lock repairs cause 14-week closure of Upper Mississippi waterway.	DTN[37]
US Gulf Coast ports	2005	W-S	Damage to ports in wake of Hurricane Katrina disrupts grain operations for several weeks.	Envision Freight[38]
	2005	W-S	Operations at major ports are severely limited for several months owing to damage from Hurricane Rita.	American Association of Port Authorities[39]
	2011	W-H/F	Thick fog brings shipping to a standstill.	ICIS News[40]
	2012	W-S	Hurricane Isaac prompts closure of major ports.	*Forbes*[41]
	2015	W-H/F	Dense fog interrupts shipping for several days.	*World Maritime News*[42]
	2015	W-H/F	Traffic in key shipping lane is halted owing to fog.	*World Maritime News*[43]
Brazil's inland roads	2008	W-F/D	Flooding and mudslides cause major road closures.	US NOAA[44]
	2011	W-F/D	Flooding and landslides destroy major roads.	US NOAA[45]

Chokepoint	Year of incident	Hazard code	Brief description	Source
	2013	P-D	Poor quality of roads causes major delays to shipment of soybean harvest to port.	BBC News[46]
	2015	P-U	Truckers blockade grain shipments along major roads in protest against high diesel prices.	Reuters[47]
	2015	P-U	Truckers strike for second time in a year over high diesel prices, blockading key transport routes.	Farm Futures[48]
	2017	W-F/D	3,000 trucks carrying soybean shipments are stranded on road following heavy rainfall.	Reuters[49]
	2017	P-U	Protesters blockade major roads linking Mato Grosso to southern ports.	Reuters[50]
Brazil's southern ports	2005	W-S	Strong winds cause Santa Catarina port to close.	IHS Fairplay[51]
	2008	W-F/D	Extreme rainfall and landslides close port of Paranaguá.	FBDS/Lloyd's[52]
	2010	P-U	Lack of capacity at Santos port causes major backlogs along roads.	BBC News[53]
	2010	P-T	Port of Paranaguá ordered to close by environmental inspectors.	Reuters[54]
	2013	W-F/D	Heavy rainfall prevents loading of soybean shipments onto ships, causing backlog of vessels waiting for several weeks to dock.	Wharton Business School[55]
	2013	P-U	Lack of capacity at major port delays shipments.	Neptune Shipping Agency[56]
	2013	P-D	Fire at Santos destroys a number of port terminals and disrupts operations.	*Independent*[57]
	2014	W-H/F	Fog causes Santos port to close for 32 hours.	Port Finance International[58]
	2015	W-S	Powerful waves prompt major port to close its operations.	*JOC*[59]
	2015	P-D	Fire at Santos port prevents access for trucks.	Reuters[60]
	2016	P-D	Fire damages infrastructure and blocks access to Santos port.	Reuters[61]
	2016	P-U	Dockworker strikes disrupt operations at Santos port.	LinkedIn[62]
	2016	W-S	Rough seas cause Santos port to close.	*JOC*[63]
	2016	W-F/D	Flooding closes Santos port.	*JOC*[64]
	2016	W-H/F	Dense fog delays grain-handling operations at Santos port.	*JOC*[65]
Black Sea rail network	2009	W-F/D	Flooding causes serious damage and delays to rail infrastructure and operations in Ukraine and Romania.	Railway Pro[66]
	2011	P-U	Rail shipments of grain are temporarily suspended owing to backlogs at port.	Agrimoney[67]
	2012	W-F/D	Grain rail shipments en route to Russian port of Novorossiysk are halted by flooding.	Reuters[68]

Chokepoint	Year of incident	Hazard code	Brief description	Source
	2014	W-S	Heavy snowfall causes delays to rail operations in Romania.	Sky News[69]
	2014	P-T	Russia limits grain rail loadings and tightens quality controls, interrupting wheat exports.	Reuters[70]
	2014	S-C	Armed conflict brings frequent disruptions to Ukraine's railways.	WIIW[71]
	2015	S-C	Armed conflict severely damages Ukraine's railways.	TASS[72]
	2016	S-C/A	Politically motivated cyberattacks are waged against a Ukraine railway operator.	Info Security[73]
	2016	W-S	Heavy snowfall disrupts rail movements across Ukraine.	Xinhua[74]
	2016	P-U	Bumper harvest exceeds carrying capacity of Ukraine's railways, causing major backlogs and delays.	Bloomberg[75]
	2017	S-C	Humanitarian operations are disrupted as railways are blockaded.	ReliefWeb[76]
Black Sea ports	2008	P-U	500 port workers strike for 12 days at port of Constanta in Romania.	Eurofound[77]
	2010–11	P-T	Russia bans grain exports for 11 months.	*Financial Times*[78]
	2010	P-T	A de facto ban interrupts grain exports from Ukraine's primary ports.	Port Strategy[79]
	2011	P-U	Russia restricts rail shipments of grain into Novorossiysk port owing to export backlog in which silos reach full capacity.	Agrimoney[80]
	2011	W-H/F	Dense fog closes Constanta port in Romania.	Nine O'Clock[81]
	2011	W-S	Stormy weather slows operations in Russian port of Novorossiysk and contributes to backlog along railways leading to port.	*Financial Times*[82]
	2012	W-T	Freezing temperatures and strong winds result in delays of two days for vessels entering key ports in Russia and Ukraine.	*World Maritime News*[83]
	2012	W-F/D	Heavy rain floods port of Novorossiysk and temporarily halts shipping	US NOAA[84]
	2014	P-T	Ukraine closes its Crimean ports to international shipping amid crisis with Russia.	Seatrade Maritime News[85]
	2014	S-C	Ukraine loses 22 per cent of its port capacity as a result of annexation of Crimea by Russia.	Lloyd's List Maritime Intelligence[86]
	2015	P-U	Russia tightens quality control checks and delays issuance of documents at key ports.	Reuters[87]
	2016	W-S	Primary ports in Romania and Bulgaria are forced to close owing to heavy snowfall and strong winds.	Reuters[88]
	2016	W-S	Strong winds halt operations at port of Constanta in Romania for several days.	Independent Balkan News Agency[89]
	2017	W-T	Freezing temperatures, ice and gales interrupt vessel movements in major ports in Ukraine, Romania and Bulgaria.	Bloomberg[90]

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Abbreviations and Acronyms

AIS	Automatic Identification System
AMIS	Agricultural Market Information System
BEC	Broad Economic Categories
CH-FSD	Chatham House Food Security Dashboard
CH-MAT	Chatham House Maritime Analysis Tool
CHRTD	Chatham House Resource Trade Database
DAP	diammonium phosphate
EIA	Energy Information Administration
EIU	Economist Intelligence Unit
FAO	Food and Agriculture Organization of the United Nations
FEWS NET	Famine Early Warning Systems Network
GCC	Gulf Cooperation Council
HS	Harmonized Commodity Description and Coding System
IEA	International Energy Agency
IMTS	International Merchandise Trade Statistics
IOC	international oil company
ISIS	Islamic State of Iraq and Syria
ITF	International Transport Forum
JODI	Joint Organisations Data Initiative
K	potassium
LIFDC	low-income food-deficit country
MAP	monoammonium phosphate
MENA	Middle East and North Africa
MOP	muriate of potash
MoU	memorandum of understanding
N	nitrogen
NGO	non-governmental organization
NOAA	National Oceanic and Atmospheric Administration
NSR	Northern Sea Route
NWP	Northwest Passage
OECD	Organisation for Economic Co-operation and Development
P	phosphate
PIANC	World Association for Waterborne Transport Infrastructure
SITC	Standard International Trade Classification
SPR	Strategic Petroleum Reserve
UAE	United Arab Emirates
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea
UNCTAD	United Nations Conference on Trade and Development
USAID	United States Agency for International Development
USDA	US Department of Agriculture
WFP	World Food Programme
WTO	World Trade Organization

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Acknowledgments

Special thanks go to Johanna Lehne (Chatham House) for her invaluable research and data analysis; and to Richard King (Chatham House) for the development of the Chatham House Food Security Dashboard and for his comments on earlier drafts. Thanks also go to Professor Paul Stevens (Chatham House) for his analysis in the report.

The Chatham House Maritime Analysis Tool (CH-MAT) was developed by Laura Wellesley and Felix Preston (Chatham House); the authors thank Felix for his guidance and contributions from the start of this research.

Thanks also go to Dr Tristan Smith (University College London), Dr Conor Walsh (University of Manchester) and Dr Michael Traut (University of Manchester) for their early review of the Chatham House Maritime Analysis Tool, their reflections on preliminary findings, and their comments on an earlier draft of the report. Many thanks go to Professor Tim Benton (Chatham House), Cleo Paskal (Chatham House), Bernice Lee (Chatham House), Rear Admiral Neil Morisetti (University College London), Captain Andrew Tucci (US Coast Guard), and two anonymous reviewers for their comments on an earlier draft of the report.

The authors are grateful to Jake Statham for his enthusiastic and meticulous editing of the report; to Amy Barry for her valuable guidance and support with media outreach; to Nick Capeling, Gitika Bhardwaj, Thomas Farrar, Jessica Pow and Lisa Toremark for their help with the digital launch; and to Autumn Forecast at Soapbox for her work on the design and production of the report.

We thank the team at Applied Works and Johanna Lehne for their expertise in translating our research into the interactive microsite 'resourcetrade.earth'.

We are also very grateful for the insights of those who participated in our workshop, 'Anticipating and Mitigating Major Disruptive Risks to Global Food Trade', held in London on 21 September 2015.

Many members of the Chatham House Energy, Environment and Resources Department – both staff and interns – provided research and administrative support throughout the process: first and foremost, Rachel Shairp and Ruth Quinn; together with Jaakko Kooroshy, Gemma Green, Elena Bignami, Anna Bordon, Claire Duval, Emilie Hobbs, Giulia Nicolini, Liam O'Flaherty, Ying Qin, Naomi Smith and Gemma Wardle.

Finally, thanks go to the MAVA Foundation for its generous support of this research.

Development of Chatham House's 'resourcetrade.earth' was led by Felix Preston, Richard King and Siân Bradley. The underlying Chatham House Resource Trade Database builds on an earlier version developed by Jaakko Kooroshy.

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Charity Registration Number: 208223

ISBN 978-1-78413-230-9