Network Quality and Environment Framework

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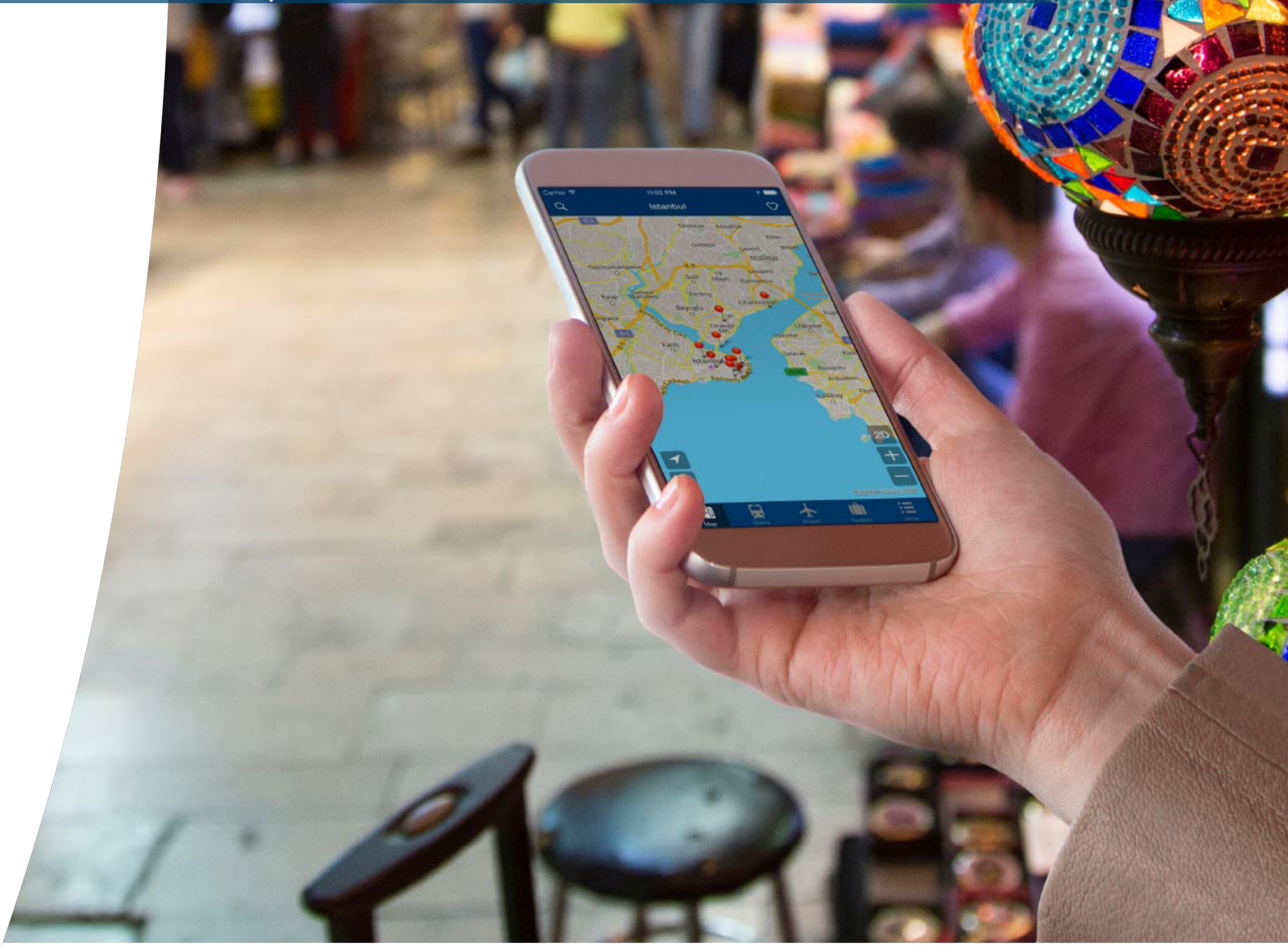

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Summary

The aviation policy of the Dutch Government aims to improve (1) the business climate, (2) the competitive position of AMS and (3) the wellbeing of the Dutch population. To measure the role of network development in achieving these three goals, the Dutch government seeks to develop a new network quality indicator (NQI). Ministerie van Infrastructuur en Waterstaat (2022b) defines Network Quality as "the availability of direct connections to preferred destinations. Preferred destinations are cities that represent a significant economic importance for the Netherlands or that have a special political/historical relationship with the Netherlands." Preferred cities are determined based on the Globalization and World Cities-index (GaWC; Taylor, 2023). The network quality is the sum of the capacity offered on direct flights times the GaWC score for each preferred city. We designate the indicator proposed by the ministry of Infrastructure and Water management (I&W) with NQI_{GaWC}. Added to this, we assume a fourth goal of aviation policy is the accessibility for inbound tourists to the Netherlands to contribute to the Dutch economy. We define net economic impacts as the broader economic impacts minus the externalities caused by environmental issues. For this study, we just accounted for CO_2-emissions as externality, assuming that CO_2 has a strong relationship with network, while or instance noise and air quality are mainly related to the number of flights, not the distances covered. Part of the Dutch environmental policy with respect to air transport is a planned de-growth of Schiphol Airport. Because we presume that the NQI will play a role in the political discussion about the acceptability of growth or degrowth, we added in our study a fifth goal for the NQI, which is to enable determining the most efficient way to degrow the airport.

Overall, for our study, we assume the following goals for a network (or aviation) quality indicator (the first three are those from I&W):

1. improve the business climate
2. improve the competitive position of AMS
3. enhance the well-being of the Dutch population (outbound travel)
4. assess the revenues for the Dutch economy of all three types of passengers (outbound travellers, inbound visitors and transfer)
5. enable determining the most efficient way to degrow Schiphol airport.

Based on these considerations, this study aims to determine the relationship between international connectivity quality indicators, such as the I&W proposed NQIGaWC, and the net economy and to what extent such indicators enable the *determination of optimum slot reduction pathways.*

This goal translates into the following research questions:

1. What are common network quality indicators for air transport?
2. How does the I&W proposed NQI_{GaWC} compare to indicators found in the literature?
3. What is the relationship between direct and indirect economic effects and network quality indicators?
4. How can a network quality indicator inform a de-growth policy?
5. What is the impact on results when integrating all international transport modes into one indicator?
6. What is the effect on results when incorporating environmental costs into the indicator?

A review of the aviation and network-related literature about network quality (chapter 2) revealed different metrics to characterize a network, including the number of direct connections, the number of stops required to reach a destination, and one that measures the importance of a node by taking into account the volume (measured in, for example, the number of connections) of the other nodes to which it is connected. A node is important if many other nodes connect to it. The metrics say something about "the extent to which the Netherlands connects to the rest of the world" (Ministerie van Infrastructuur en Waterstaat, 2022b, p. 1). Accessibility is a common concept in the literature and measures the ease of reaching destinations as a function of travel time, monetary costs, external costs, etc. This concept is particularly related to airline behaviour because airlines determine some if not all, factors.

Chapter 1 describes how the Ministry defines network quality, focusing on the exogenous added value to the Netherlands of individual destinations. This added value is not corrected for negative externalities. This chapter

aims to review the literature on the environmental implications of varying network designs (and associated costs) that may achieve the same benefits (revenues). The literature points out that "hubbing" negatively affects the environment compared to a point-to-point network.

Airport and air service quality can affect demand and, therefore, the economic benefits of air travel discussed in chapter 3. To determine the effect of a network on the economy, a network quality indicator depending on airline or airport behaviour alone can only do so in an indirect way. Chapter 3 explores the relationship between aviation, air connectivity and the economy. The Ministerie van Infrastructuur en Waterstaat (2022b) develops a network quality indicator because it assumes air connectivity improves the business climate, the competitive position of the Dutch economy and the wellbeing of Dutch travellers. Taking this view as a starting point, we examined how to measure economic benefits and how they depend on the airline sector's behaviour. Common findings are that aviation and economy, for instance, GDP, employment, and indirect effects, are positively related, but only a few studies address causality. Theoretically, the direct effect measures increased net surplus in the transport market, and this direct effect will pass on to the final users as the indirect effect. Accounting for additional indirect effects would cause double counting in a perfect market. However, in reality, the market is imperfect. If the transport company prices exceed marginal costs, there might be an additional positive indirect effect (over the direct effect). But as aviation markets are large international markets, benefits of outbound travellers partly accrue at the destination and transfer passengers at the origin and destination, but not much at the transfer airport. The findings above imply that an analysis of network quality must precisely define which economic effects are important, where they come from, and how well the indicator relates to such impacts.

Chapter 5 synthesises the findings from the literature and suggests alternative indicators. These findings first revealed inconsistencies in the aims of I&W with the new quality indicator and its definition. For instance, I&W states the indicator does not measure hub performance. Still, it uses selected cities and the number of seats the network offers them, typically used to measure hub-performance. Also, the quality indicator does not aim to describe airline behaviour, but its components – preferred cities and seat-capacity supply - still depend on airline behaviour network setting pricing. The goal of benefitting the economy demands to include externalities. Also, the GaWC system tends to include only the importance for specific sectors (business travel, financial and business sectors), ignoring others (like inbound leisure tourism). We propose applying an indicator that directly relates to direct net-economic impacts for all international connectivity by all transport modes and also considers environmental costs.

In Chapter 6, we explore to what extent a network quality indicator, like the one proposed by the ministry, relates well to the higher-level political goals and alternatives for such an indicator. First, 39% of all direct destinations to AMS have a GaWC rating <10. These cities receive 11% of all flights. Furthermore, the GaWC index appears to have a weak relationship with the current number of direct flights from AMS. This difference may be caused by the priority given to certain businesses in drafting the GaWC, for instance, largely ignoring outbound and inbound holidaymakers. This one-sidedness makes the GaWC less suitable for overall economic and social goals formulated by I&W. The other element in the I&W proposed indicator is the current air-lift supply. Also, this part is less suitable for the ministry's goals because airlines do not only optimise connections based on important cities for the Netherlands, originating from or travelling to the Netherlands, but also optimise for demand and maximising profits from transfer passengers. Our study reveals this deficiency (see further down). More importantly, based on a Lorenz-graph to determine unequal contributions of certain connections to the Dutch direct net-economy, we found that the I&W proposed indicator NQI_{GaWC} treats all current connections highly equally, meaning that adding 1% of randomly chosen destinations to the network will in general add 1% to the value of the indicator. The indicator is, therefore, not helpful in determining or guiding AMS's growth or de-growth. Adding rail connections increases NQI_{GaWC} by 47%. It causes the relationships between economic revenues and the number of connections to become positively correlated, while this is for flights from AMS hardly the case.

We then explored whether direct revenues (spending of travellers within the Dutch economy) relate to GaWC and found it does not. Therefore, we also looked at the current network for some additional analyses. Adding externalities for aviation GHG emissions reduces direct revenues from flights by 26% but does not improve the relationship with GaWC. A Lorenz plot of total direct revenues corrected for climate impacts to flights from AMS reveals the 30% of flights with the lowest net-revenues add nothing to the overall revenues and form the first candidates to remove in case of de-growth. We also explored the relationship between trade balance and volume.

Still, we did not find a strong relationship with the passengers carried through the current network at Schiphol or the international network for all transport modes. The reason might be that the business travel generated by different sectors varies greatly, partly independent from the trade flows. Therefore, trade seems to be a less suitable indicator for the economic impact of the AMS network.

Finally, we explored several other network quality indicators like the GACI (global aviation connectivity index), which does not show a clear relationship with number of flights from AMS. Still, two other indicators proposed in the literature, Betweenness and Degree Centrality, show a positive relationship with the number of flights (including transfers) but not for total travel volumes of O/D-travellers (excluding transfers). This finding shows these two indicators represent pure network quality but do not relate to the travel by air starting or ending in The Netherlands, making them less promising for further application.

Our recommendation is to develop a more policy-relevant indicator, an 'International Connectivity Impact Indicator' (ICII), rather than just the network quality. The ICII should measure direct revenues to the Dutch economy, include the revenues generated by all other transport modes and show net economic revenues corrected for externalities. A well-developed ICII much better informs policymakers and the industry on how best to arrange growth or de-growth of air travel and other transport modes to have the best impacts on the wider economy. With this recommendation, the focus will shift from the hub-function to an integrated tool based on real travel behaviour, connectivity, and direct economic benefits.

Samenvatting

Het luchtvaartbeleid van de Nederlandse overheid is gericht op het verbeteren van (1) het vestigingsklimaat, (2) de concurrentiepositie van Luchthaven Schiphol Amsterdam en (3) het welzijn van de Nederlandse bevolking. Om de rol van netwerkontwikkeling bij het bereiken van deze drie doelen te meten, wil de Nederlandse overheid een nieuwe netwerkkwaliteitsindicator (NQI) ontwikkelen. Het Ministerie van Infrastructuur en Waterstaat (2022b) definieert netwerkkwaliteit als "de beschikbaarheid van directe verbindingen naar preferente bestemmingen. Preferente bestemmingen zijn steden die een aanzienlijk economisch belang voor Nederland vertegenwoordigen of die een bijzondere staatkundige/historische relatie met Nederland hebben." Voorkeurssteden worden gekozen op basis van de *Globalization and World Cities*-index (GaWC; Taylor, 2023). De netwerkkwaliteit is de som van de capaciteit die wordt aangeboden op directe vluchten maal de GaWC-score voor elke voorkeursstad. De indicator die het ministerie van Infrastructuur en Waterstaat (I&W) voorstelt, duiden we met NQI_{GaWC} aan. Daarnaast gaan we ervan uit dat een vierde doel van het luchtvaartbeleid de toegankelijkheid is voor inkomende toeristen naar Nederland die fors bijdragen aan de Nederlandse economie. We definiëren netto economische effecten als de bredere economische effecten minus de externe effecten veroorzaakt door milieukwesties. Voor deze studie hebben we alleen rekening gehouden met CO_2-emissies als externe kosten, ervan uitgaande dat CO_2 een sterke relatie heeft met de afgelegde afstanden in het netwerk, terwijl bijvoorbeeld geluid en luchtkwaliteit voornamelijk verband houden met het aantal vluchten. Onderdeel van het Nederlandse milieubeleid ten aanzien van het luchtvervoer is een geplande reductie van de maximale capaciteit van de luchthaven Schiphol. Omdat we veronderstellen dat het NQI een rol zal spelen in de politieke discussie over de aanvaardbaarheid van groei of *de-growth*, hebben we in onze studie een vijfde doel voor het NQI toegevoegd, namelijk het mogelijk maken om de meest efficiënte manier te bepalen om de luchthaven te laten krimpen.
Over het algemeen gaan we voor ons onderzoek uit van de volgende doelen voor een netwerk- of luchtvaartkwaliteitsindicator (de eerste drie zijn gelijk aan die van I&W):

1. Verbeteren van het vestigingsklimaat
2. De concurrentiepositie van AMS te verbeteren
3. Het welzijn van de Nederlandse bevolking te vergroten (uitgaand reizen)
4. De inkomsten voor de Nederlandse economie van alle drie de typen passagiers (uitgaande reizigers, inkomende bezoekers en transfer passagiers) in kaart te brengen.
5. Het mogelijk maken om te bepalen wat de meest efficiënte manier is om Schiphol te krimpen.

Op basis van deze overwegingen heeft de studie tot doel de relatie te bepalen tussen internationale connectiviteitskwaliteitsindicatoren, zoals de door I&W voorgestelde NQI_{GaWC}, en de netto-economie en in hoeverre dergelijke indicatoren het mogelijk maken om *optimale slotreductietrajecten te bepalen.*
Dit doel vertaalt zich in de volgende onderzoeksvragen:

1. Wat zijn gemeenschappelijke indicatoren voor de kwaliteit van het netwerk voor het luchtvervoer?
2. Hoe verhoudt de door I&W voorgestelde NQI_{GaWC} zich tot indicatoren in de literatuur?
3. Wat is de relatie tussen directe en indirecte economische effecten en indicatoren voor netwerkkwaliteit?
4. Hoe kan een netwerkkwaliteitsindicator een groeibeleid informeren?
5. Wat is het effect op de resultaten als alle internationale vervoerswijzen in één indicator worden geïntegreerd?
6. Wat is het effect op de resultaten bij het opnemen van milieukosten in de indicator?

De luchtvaart- en netwerk gerelateerde literatuur over netwerkkwaliteit (hoofdstuk 2) beschrijft verschillende variabelen om een netwerk te karakteriseren, waaronder het aantal directe verbindingen, het aantal tussenstops dat nodig is om een bestemming te bereiken, en een die het belang van een knooppunt meet door rekening te houden met het volume (gemeten in bijvoorbeeld het aantal verbindingen) van de andere knooppunten waarmee het is verbonden. Een knooppunt is belangrijk als er veel andere knooppunten op aansluiten. De variabelen zeggen iets over "de mate waarin Nederland zich verbindt met de rest van de wereld" (Ministerie van Infrastructuur en Waterstaat, 2022b, p. 1). Toegankelijkheid is een veelgebruikt begrip in de wetenschappelijke

literatuur en meet het gemak waarmee bestemmingen worden bereikt als functie van reistijd, reiskosten, externe kosten, enz. Dit concept houdt met name verband met het gedrag van luchtvaartmaatschappijen, omdat luchtvaartmaatschappijen sommige, zo niet alle, factoren bepalen.

Hoofdstuk 1 beschrijft hoe het ministerie netwerkkwaliteit definieert, waarbij de nadruk ligt op de exogene toegevoegde waarde voor Nederland van individuele bestemmingen. Deze toegevoegde waarde wordt niet gecorrigeerd voor negatieve externaliteiten. Dit hoofdstuk heeft tot doel een overzicht te geven van de literatuur over de milieu-implicaties van verschillende netwerkontwerpen (en bijbehorende kosten) die dezelfde voordelen (opbrengsten) kunnen opleveren. De literatuur wijst erop dat "hubbing", het vervoeren van passagiers naar een grote 'hub' zoals Schiphol, en vandaar na een overstap weer verder naar de uiteindelijke bestemming, een negatieve invloed heeft op het milieu in vergelijking met een netwerk op basis van verbindingen zonder overstap (punt-op-punt netwerk).

De kwaliteit van de luchthaven- en de aangeboden verbindingen door de lucht kan van invloed zijn op de vraag en dus op de economische bijdragen van vliegreizen (zie hoofdstuk 3). Om het effect van een netwerk op de economie te bepalen, kan een indicator voor de kwaliteit van het netwerk die alleen afhankelijk is van het gedrag van de luchtvaartmaatschappij of de luchthaven, dit alleen op indirecte wijze doen. Hoofdstuk 3 onderzoekt de relatie tussen luchtvaart, luchtverbindingen en de economie. Het Ministerie van Infrastructuur en Waterstaat (2022b) ontwikkelt een netwerkkwaliteitsindicator omdat het ministerie ervan uitgaat dat luchtverbindingen het vestigingsklimaat, de concurrentiepositie van de Nederlandse economie en het welzijn van Nederlandse reizigers verbeteren. Met deze visie als uitgangspunt onderzochten we hoe economische voordelen kunnen worden gemeten en hoe deze afhangen van het gedrag van de luchtvaartsector. Veel voorkomende bevindingen zijn dat luchtvaart en economie, bijvoorbeeld het bbp, de werkgelegenheid en indirecte effecten, positief met elkaar in verband staan, maar slechts enkele studies richten zich op causaliteit. Theoretisch leidt het directe effect tot een toename van het netto-overschot op de vervoersmarkt, en dit directe effect zal als indirect effect worden doorgegeven aan de eindgebruikers. Rekening houden met extra indirecte effecten zou leiden tot dubbeltelling in een perfecte markt. In werkelijkheid is de markt echter niet perfect. Als de prijzen van de transportbedrijven hoger zijn dan de marginale kosten, kan er een bijkomend positief indirect effect zijn (over het directe effect). Maar aangezien luchtvaartmarkten grote internationale markten zijn, ontstaan de voordelen van uitgaande reizigers deels op de bestemming en van transferpassagiers op de plaats van vertrek en bestemming, maar nauwelijks op de transferluchthaven. De bovenstaande bevindingen impliceren dat een analyse van de netwerkkwaliteit nauwkeurig moet definiëren welke economische effecten belangrijk zijn, waar ze vandaan komen en hoe goed de indicator zich verhoudt tot dergelijke effecten.

Hoofdstuk 5 maakt een synthese van de bevindingen uit de literatuur en stelt alternatieve indicatoren voor. Deze bevindingen brachten in de eerste plaats inconsistenties aan het licht in de doelstellingen van I&W met de nieuwe kwaliteitsindicator en de definitie ervan. I&W geeft bijvoorbeeld aan dat de indicator de prestaties van de hub niet meet. Toch worden vooraf geselecteerde steden en het aantal stoelen dat het netwerk hen biedt, meestal gebruikt om de prestaties van de hub te meten. Hoewel de kwaliteitsindicator niet bedoeld is om het gedrag van luchtvaartmaatschappijen te beschrijven, zijn de componenten ervan - voorkeurssteden en het aanbod van stoelcapaciteit - nog steeds afhankelijk van het gedrag van luchtvaartmaatschappijen die de prijzen vaststellen. Om te bekijken in hoeverre het doel, de economie te stimuleren, wordt bereikt vereist dat externe effecten worden meegenomen. Het GaWC-systeem heeft de neiging om alleen het belang voor specifieke sectoren (zakenreizen, financiële en zakelijke sectoren) op te nemen, waarbij andere sectoren (zoals inkomend vrijetijdstoerisme) worden genegeerd. Wij stellen voor een indicator toe te ontwikkelen die rechtstreeks de directe netto-economische effecten bevat voor alle internationale connectiviteit door alle vervoerswijzen en rekening houdt met de milieukosten.

In hoofdstuk 6 onderzoeken we in hoeverre een netwerkkwaliteitsindicator, zoals die door het ministerie wordt voorgesteld, goed aansluit bij de bovenliggende politieke doelen en alternatieven voor een dergelijke indicator. Ten eerste heeft 39% van alle directe bestemmingen naar AMS een GaWC-rating <10. Deze steden ontvangen 11% van alle vluchten. Bovendien lijkt de GaWC-index een zwakke relatie te hebben met het huidige aantal rechtstreekse vluchten vanaf AMS. Dit kan worden veroorzaakt door het gegeven dat in het GaWC-systeem bepaalde sectoren prioriteit krijgen, waardoor uitgaande en inkomende vakantiegangers grotendeels worden genegeerd. Deze eenzijdigheid maakt de GaWC minder geschikt voor de door I&W geformuleerde algemene economische en maatschappelijke doelen. Het andere element in de door I&W voorgestelde indicator is de huidige luchttoevoer. Ook dit onderdeel is minder geschikt voor de doelstellingen van het ministerie, omdat luchtvaartmaatschappijen niet alleen verbindingen optimaliseren op basis van voor Nederland belangrijke steden, en reizigers afkomstig uit of reizend naar Nederland, maar ook vooral voor het maximaliseren van de opbrengsten inclusief de (capaciteits-)winst van transferpassagiers. Onze studie brengt deze tekortkoming aan het licht (zie verderop). Belangrijker nog, op basis van een Lorenz-grafiek om de ongelijke bijdragen van bepaalde verbindingen aan de Nederlandse directe netto-economie te bepalen, vonden we dat de door I&W voorgestelde indicator NQI_{GaWC} voor alle huidige verbindingen weinig variatie biedt. Dat betekent dat het toevoegen van 1% vluchten naar een willekeurig gekozen bestemmingen aan het netwerk in het algemeen ook ongeveer 1% aan de waarde van de indicator zal toevoegen. De indicator helpt daarom niet bij het bepalen of sturen van de groei of krimp van Luchthaven Schiphol. Voorts vonden we dat het toevoegen van internationale spoorverbindingen de score van de NQI_{GaWC} met 47% verhoogt. Ook blijkt dat wanneer rail wordt meegenomen, de relatie tussen economische inkomsten en het aantal verbindingen positief wordt, terwijl dit voor alleen vluchten vanaf Schiphol nauwelijks het geval is.

Ook zagen we dat de directe inkomsten (bestedingen van reizigers binnen de Nederlandse economie) geen verband houden met GaWC. Daarom hebben we enkele aanvullende analyses uitgevoerd. Het toevoegen van externaliteiten voor de uitstoot van broeikasgassen in de luchtvaart vermindert de directe inkomsten uit vluchten met 26%, maar verbetert de relatie met GaWC niet. Een Lorenz-grafiek van de totale directe inkomsten, gecorrigeerd voor de klimaateffecten van vluchten vanaf Schiphol, laat zien dat de 30% van de vluchten met de laagste netto-inkomsten niets toevoegen aan de totale directe inkomsten en derhalve bij krimp in aanmerking kunne komen om weg te vallen. We onderzochten ook de relatie tussen handelsbalans en het aantal passagiers op het huidige netwerk op Schiphol en via het internationale netwerk voor grondgebonden vervoerswijzen. De reden kan zijn dat de zakenreizen die door verschillende sectoren worden gegenereerd, sterk variëren, onafhankelijk van het handelsvolume. Handel lijkt dan ook een minder geschikte indicator voor de economische impact van het AMS-netwerk.

Ten slotte onderzochten we verschillende andere indicatoren voor netwerkkwaliteit, zoals de GACI (*Global Aviation Connectivity Index*), die geen duidelijke relatie laat zien met het aantal vluchten van AMS. Toch laten twee andere indicatoren die in de literatuur worden voorgesteld, *Betweenness* en *Degree Centrality*, een positieve relatie zien met het aantal vluchten (inclusief transfers), maar niet met het totale reisvolume van reizigers op deze relaties (exclusief transfers). Deze bevinding toont aan dat deze twee indicatoren de zuivere netwerkkwaliteit vertegenwoordigen, maar geen betrekking hebben op het vliegverkeer dat in Nederland begint of eindigt, waardoor ze minder veelbelovend zijn voor verdere toepassing.

Onze aanbeveling is om een meer beleidsrelevante indicator te ontwikkelen, een '*International Connectivity Impact Indicator*' (ICII), in plaats van alleen de netwerkkwaliteit. De ICII moet de directe inkomsten voor de Nederlandse economie meten, de inkomsten van alle andere vervoerswijzen omvatten en de netto economische inkomsten laten zien, gecorrigeerd voor externe effecten. Een goed ontwikkelde ICII informeert beleidsmakers en de industrie veel beter over hoe de groei of krimp van het luchtvervoer en andere vervoerswijzen het beste kan worden georganiseerd om met de minste schade voor de economie. Met deze aanbeveling verschuift de focus van de hub-functie naar een geïntegreerde tool op basis van reëel reisgedrag, connectiviteit, alle vervoerwijzen, milieukosten en directe bijdragen aan de economie.

Index

1 Introduction

Objective

This chapter introduces the background to the new network quality indicator proposed by the Dutch Transport Ministry (I&W), discusses some critiques, and describes the objective of and further layout of this report.

Key findings

- The I&W proposed indicator combines the value of each direct connection to AMS with the number of seats offered and sums it to one network quality indicator (NQI).
- The purpose of the NQI is to help assess the three goals of the network: improve the business climate, the competitive position of AMS and the well-being of the Dutch population.
- Critiques urge to extend the indicator to include connectivity with all transport modes and direct net-economic impacts. The latter means to reduce the gross economic impacts with the environmental damages.
- We have added to the goals that the indicator should also inform the de-growth policy currently applied to AMS. The indicator should help answer the question of which connections to remove, causing the least damage to the economic and well-being goals.
- The goal of this study is to determine the relationship between international connectivity quality indicators, such as the I&W proposed NQI_{GaWC}, and the economy and to what extent such indicators enable the determination of optimum slot reduction pathways.

The Dutch government intends to develop a new indicator for 'network quality' (Ministerie van Infrastructuur en Waterstaat, 2020, p. 10) in an attempt "to give as much priority as possible to aviation with the greatest possible value for the Dutch economy and employment." Network quality may have different meanings to different stakeholders. In the description mentioned above, we can distinguish between "purpose" (the greatest possible value for the Dutch economy) and the "tool" (the aviation network). More in detail, I&W observe that air connectivity serves three main purposes: improving the business climate, the competitive position of the Dutch economy and the wellbeing of Dutch travellers. But then the Ministry narrows the purpose (connectivity for international accessibility, economy and wellbeing) to "network quality indicates the extent to which the Netherlands connects to the rest of the world" (Ministerie van Infrastructuur en Waterstaat, 2022b, p. 1). The Ministry assumes that it has no power to change slot use and only limited power to reduce the overall number of slots. However, it also states that it will aim at the European negotiations in Brussels in the context of the new slot regulation being developed (planned in quarter 3, 2023) for legislation that enables more power over slots by national governments.

Previous network quality monitors (e.g. Boonekamp & Winkelmolen, 2021) reported a range of quality indicators like the number of direct flights, indirect connections, connectivity to Global Cities, and hub size compared to other hubs. The new proposed Network Quality Indicator (NQI_{GaWC}, see Box below) is a single indicator calculated with only two parameters: (1) direct connection seat capacity to a selective list of 'important' cities and (2) the GaWC (Global and World Cities) score of those cities. This way, it combines the economic value (important cities index) with one network quality parameter (the direct connections capacity).

Another issue forms the proposed de-growth policy for Schiphol (Ministerie van Infrastructuur en Waterstaat, 2022a). Schiphol faces a 500,000 slots per year capacity limit, but the minister decided to reduce this ceiling to 440,000 by 2024. Environmental goals and legislation like air quality, noise nuisance, impact on nature and NOx and CO_2 emissions dictated the new capacity limit. This report is also an attempt to provide a network quality indicator as an instrument to assess whether economically optimal slot-reductions are possible. Such information can inform the discussion about the ceiling level now and in the coming years. In other words, the report also tries to find a purpose for the proposed network quality indicator.

Box: The I&W network quality indicator

I&W based its network quality indicator (NQI) on the Global and World Cities (GaWC index, Taylor, 2023; Taylor & Derudder, 2004), which provides an index for a couple of thousand cities worldwide. DeRudder created a special list of the GaWC aimed at importance for the Netherlands (see footnote 15 in Ministerie van Infrastructuur en Waterstaat, 2022b). A combination of Network Breadth (NB) and Network Depth (ND) defines the NQI. The NB describes the share of cities served with more than 50 flights per year in the network that connect to cities with a GaWC score >10 (the maximum GaWC is 106 for London). The ND describes the capacity supplied times the importance of the connected city. By taking the square root of the seating capacity, an element of 'diminishing returns' has been added, as this algorithm will value high-frequency connections relatively less than low-frequency ones.

The final network quality is the sum of all individual ND contributions times the overall NB factor. Thus, the sum of individual contributions to ND is a proxy for the contribution to the overall network quality. We will index the I&W proposed network quality indicator as follows: NQI_{GaWC}.

The combination of indicators and goals is the starting point for this paper. Determining network quality means determining how well a network fits the purpose of contributing to the political goals (or, more precisely, improving the business climate, the competitive position of the Dutch economy and the wellbeing of Dutch travellers) and the economy. And it means to show how vulnerable this goal is for the number of slots. Thus, it is necessary to think about how to measure network quality and how that fits the purpose of the network: the ability to contribute to the economy. A range of earlier reports inspired the newly proposed NQI, which we will discuss below. To form an opinion on how well a network quality indicator performs compared to others, insight into the literature on networks and economic effects is necessary.

The 'Raad voor de Leefomgeving en Infrastructuur' (RLI, 2019) advised the government to "focus on international accessibility of the Netherlands and rethink the network quality within it", but the National Aviation Policy did not implement this. Therefore, Kröger (2020, p. 1) "calls on the government to investigate (or have investigated) for how many flights there is national demand, how the Netherlands can focus exclusively on passengers and routes that are of value to the Netherlands, how the Netherlands can sufficiently connect to the world, what the minimum number of flights for this minimum is and what means of control the ministry needs to be able to manage this". In response, the Ministry proposed a method to measure network quality defining network quality as (Ministerie van Infrastructuur en Waterstaat, 2022b, p. 3) "Network quality is the availability of direct connections to preferred destinations. Preferred destinations are cities that represent a significant economic importance for the Netherlands or that have a special political/historical relationship with the Netherlands." However, this definition does not do justice to the request by the RLI (2019, p. 7), who observes, "A good aviation network is important for the international accessibility of the Netherlands. But this international accessibility is determined by the sum of all available modes of transport: air, rail, road, and water. The Council recommends thoroughly analysing how many and which connections are needed to ensure our international accessibility. The size and quality of the required aviation network in the Netherlands, i.e. of Schiphol and the regional airports together, must be a derivative of this. At present, such a coherent assessment of the aviation network is not taking place sufficiently." In other words, an indicator should include all transport modes. Furthermore, a clear distinction between origin-destination (O/D-passengers[1]) and transfer passengers is necessary to determine the real contribution to the economy. In this report, we will assess how network quality is defined, and if the definition

[1] The term O/D-passenger is defined differently in the air transport sector and the travel and tourism sector. In air transport, often an O/D-passenger is a passenger making a direct flight from airport A to airport B. In the tourism literature, the O/D-traveller is a person travelling all the way from the front-door to the destination (accommodation, location of an activity), irrespective of one or mode transport mode used to do so. In this report we always apply the latter definition and will not use O/D-passengers as the equivalent of a direct flight.

fits the purpose of the indicator and underlying policy. We will also discuss how an aviation indicator could or should relate to other transport modes, the Dutch economy, and the environmental costs.

Another implication of the discussion above is that network quality does not necessarily give value to individual connections in a network. The first step is to describe the network as completely as possible. The second step compares the indicator to "economic performance" (Chapter 6). The advantage of doing so is that we do not impose any *a priori* expectations on each destination's economic and social importance. As mentioned above, a network quality indicator's purpose is to assess the network's goals. Therefore, we must be certain that the network quality indicator measures the "network aspect" and not the outcome of airline behaviour or the economic size of cities. A connectivity measure looks at how well a node connects to other nodes within a network. Some nodes are important if they have relatively more connections. This high connectivity does not necessarily imply these are "big" nodes (measured in population, GDP, FDI, etc.), although they can be. For example, on a global scale, "Amsterdam" is not a big destination when we look at GDP, population, etc. But the airport scores well on, for example, the GACI indicator (see 2.3.1). The question then is what this means for the various economic indicators:

- What does the literature say about the measurement of "network quality"? To answer this question, we first discuss common network indicators and their use. These indicators do not necessarily apply "quality", as discussed above. However, they are still very useful because the relation between a network indicator and an economic indicator (related to the purpose of the network or policy) will show if the network serves its purpose (is of high quality).
- How should we measure the economic impact of aviation? Many papers focus on jobs, direct and indirect effects, GDP, etc. In a tight labour market, crowding out is a very relevant concept. The decision of where to work is based on wages, and the effect of the additional job for society depends on labour productivity and added value. Additional jobs are welcome if they are more productive and add more to society than existing jobs (that may eventually disappear). For example, a technology-skilled worker can work in the aviation sector or elsewhere and likely chooses the highest wage (and secondary labour conditions, status, etc.). These normally are higher for the most profitable company. But if we factor in market failure (potential emissions reductions if this worker chooses to work for a less polluting company, abnormal profits due to market power), then it is not straightforward which job is more important for society. Similar arguments apply to, for example, real estate markets.

Furthermore, the Dutch aviation market is almost exclusively international. Therefore, at least part of the benefits will accrue elsewhere, particularly in the case of transfer traffic. A transfer passenger "helps" to bring down the average cost of a flight offered, but most of the benefit will accrue at the origin or destination and not at the transfer airport. Airlines with a relatively small home market serving international and intercontinental destinations need additional 'transfer passengers' to reduce the average cost. That strategy also leads to extensive yield management, with relatively high prices (and relatively low net benefits) for passengers flying directly (Lijesen et al., 2005). The RLI (2019) suggests that the current focus on transfer traffic is a point of concern, and this is indeed the case from the perspective of net benefits and where these accrue. On the other hand, transfer passengers are necessary for many airlines to survive. So, a network quality indicator must consider the impact of potential airline behaviour on the benefits to prevent bias.

Based on these considerations, this study aims to *determine the relationship between international connectivity quality indicators, such as the I&W proposed NQI_{GaWC}, and the economy and to what extent such indicators enable the determination of optimum slot reduction pathways.* This goal translates into the following research questions:

1. What are common network quality indicators for air transport?
2. How does the I&W proposed NQI_{GaWC} compare to indicators found in the literature?
3. What is the relationship between direct and indirect economic effects and network quality indicators?
4. How can a network quality indicator inform a de-growth policy?
5. What is the impact on results when integrating all international transport modes into one indicator?
6. What is the effect on results when incorporating environmental costs into the indicator?

Below, we dive deeper into these questions. Section 2 provides the results of a literature review on network quality: what concepts are available? Section 3 discusses economic effects: how are these measured in the literature, and what do we want to measure from a policy perspective? Section 4 discusses environmental effects because different network structures may have various environmental impacts. Given that we know the current state of the art from the literature, Section 5 then discusses how the Ministry of I&W's network quality indicator differs from what we observed from the literature and why it does not accurately describe network quality. In general, the line of reasoning is as follows. A quality indicator may not aim to be an indicator of hub performance. Still, a network quality indicator that only includes selected cities and the number of seats ignores further airline behaviour (network setting (chapters 2 and 3), pricing (chapters 2 and 3), externalities (chapter 4)), and thus ignores some vital insights from the air transport literature about the broader political goals for the wish to have high-quality air network. The empirical analysis in Section 6 highlights these issues, explores the proposed NQI_{GaWC} and other indicators, and suggests a better one.

2 Network quality literature review

Objective

Review the aviation and network-related literature to provide the arguments necessary to form an opinion on the proposed network quality indicator.

Key findings

- A network in the current setting can be seen as a set of points with the location of people who want to interact and demand a service that provides the opportunities to interact.
- There are different metrics to characterize a network, including the number of direct connections, the number of stops required to reach a destination, and one that measures the importance of a node by taking into account the importance of the nodes to which it is connected.
- The metrics mentioned in the bullet point above do not automatically say anything about airline strategy other than that the airline offers a service. But they say something about "the extent to which the Netherlands connects to the rest of the world" (Ministerie van Infrastructuur en Waterstaat, 2022b, p. 1).
- Accessibility is a common concept in the literature and measures the ease of reaching destinations as a function of travel time, monetary costs, external costs, etc. This concept is related to airline behaviour because airlines determine some, if not all, factors.
- Airport and air service quality can affect demand; therefore, we discuss the benefits later.
- To determine the effect of a *network* on the economy, a network quality indicator cannot only depend on indicators for airline or airport behaviour because such metrics measure the impact of firm strategy but may fail to relate to the economic importance of the city or country connected.
- A quality indicator aiming to be an indicator of hub performance or a network quality indicator that only includes selected cities and the number of seats cannot be an indicator for the overall economic performance of the network when it ignores pricing, externalities and the direct revenues of different types of travellers.

2.1 Introduction

In the context of network quality and environment framework, the ministry of I&W uses a network quality definition to indicate "the extent to which the Netherlands connects to the rest of the world" (Ministerie van Infrastructuur en Waterstaat, 2022b, p. 1). Specifically, the definition of network quality rests on expressions for network depth and width. The network width depends on the score of a destination city on the GaWC index, whereas the network depth depends on the same score and the square root of the seating capacity (see Section 6.4 for more details). This chapter provides a theoretical background for arguments criticising the chosen quality index and the underlying policy choices. Specifically, we address the "preferential cities" and, although defending "hubbing" is not a quality index goal, airline behaviour affects the network indicator. But we start in 2.2 with the idea of the "network" itself: are we all on par with the definition of a network? Then, in 2.3, we discuss several network indicators proposed in the literature, or, in other words, different perspectives on network quality. In 2.4, we conclude (this part) and provide a theoretical view of what we exactly mean by network quality. In later chapters, we compare this to the definition used by the Ministry of I&W.

2.2 Aviation networks

In policy-making, the "network" can consist of nodes (destinations and routes, each of which connects two nodes. The aviation network comprises airports (nodes) and flights (routes). Combining flights through transfers can increase the number of airports reachable from one airport. The air transport network enables travellers and freight to overcome distances by using fast transport relatively quickly (Allroggen et al., 2013). But the monetary

and time costs are more than the time and cost of the flight. So, we may extent the aviation network by including airport access and regress modes.
The aviation network itself is part of a bigger transport network that includes competitors to the aviation network. Furthermore, the aviation network does not serve all destinations unless we apply broad definitions of access and regress modes.[2] The network quality drives the value of transportation links for the economy. In that sense, realising that a transport network is part of an even bigger network is important. Economic agents, business people, and people need to interact, resulting in a derived demand for travel. It is the interaction that brings value (discussed in the next section), and the transportation system enables the interaction. The transportation system enables or even generates interactions (transactions) or makes existing interactions easier and thus adds value. The value derives from the interaction or transaction, not the link or aviation network offered. To put this into context, Eagle et al. (2010) mention the benefits of social networks (access to jobs, greater job mobility, higher salaries, opportunities for entrepreneurship, and increased power in negotiations). Eagle et al. (2010) study the relation between social network structure and economic development by looking at the relation between the social network (obtained from data from the UK) national communication network) and socioeconomic indicators. Specifically, Eagle et al. (2010) consider social and spatial diversity of communication within a person's social network. High diversity means a person's time is spread more evenly over social connections and regions. To illustrate the importance of looking at diversity, we summarize some of the findings from Eagle et al. (2010). The monthly call volume is above the national average in a less prosperous region, while the network diversity is low. On the other hand, in a prosperous region, inhabitants have "extremely diverse networks", although call volumes are not above the national average. Eagle et al. (2010) conclude that social network diversity is an important indicator of economic development, although the causal direction is unclear.
This discussion of Eagle et al. (2010) serves one purpose: network diversity is an important indicator. It provides the opportunities for connecting, not the factual connections made. Of course, this research used data from the U.K. national communication network and not an international aviation market. But these networks serve similar purposes: they allow people to link with each other for business or leisure, just like an aviation network.[3] Further research must show if using aviation data delivers similar conclusions concerning network diversity. If this were true, diversity (a balanced spread of activities over many connections) and not necessarily a high volume would be important. The network depth part of the NQI_{GaWC} acknowledges this effect by taking the square root of the capacity on each route, which reduces the effect of adding capacity to an existing connection compared to opening a new one. Compare Bilotkach (2015), who concludes that the number of destinations is a more important determinant of local employment and business establishments than traffic volume in the U.S. To facilitate such research for the Dutch case, we first must have a clear idea of the economic effects to be measured (the socioeconomic indicators mentioned by Eagle et al. (2010), and we need to realize the network itself is just a tool to accommodate social and economic interaction.
Therefore, to conclude this subsection, "the network" is the set of locations where people who want to interact and demand a service that allows them - provides the opportunities - to interact. Note that this is quite different from the network quality indicator we have seen in the past (which largely depends on volume) and is more in line with the current way of thinking about preferential destinations: to which cities do we want to be connected? More specifically, "network quality indicates the extent to which the Netherlands connects to the rest of the world" (Ministerie van Infrastructuur en Waterstaat, 2022b, p. 1). The next subsection addresses this type of network quality (the extent to which a city is connected) in more detail. One of the ways to look at that is by considering connectivity.

[2] The EU looks at relevant markets and airport catchment areas in studies of airport market power. We will not do that in the current study, but it is important to mention that the "aviation network" is part of a bigger network.
[3] Business meetings can now be done online rather than face-to-face, just like international friends or family members can talk to each other online or face-to-face. So, while it seems silly to compare a phone market to an aviation market, the underlying concepts (networks, connections, interaction) are similar.

2.3 Measuring Network Quality

Policymakers and airline and airport decision-makers often refer to operational metrics such as the number of available destinations, flight frequencies, seat capacity and volumes to quantify the quality of airline networks and the links to the economy around a particular airport (Brueckner, 2003). However, these metrics can be misleading as they can be an obstacle to understanding the quality of the air transport networks used by passengers to travel from a particular airport, as they do not capture the overall attributes of network quality (Lenaerts et al., 2020) mention attributes such as travel purpose or the potential connected destinations to other airports because existing metrics of traffic volumes provide little information about the economic effect. For example, a share of airport activity nowadays can be focused on leisure purposes, which only provide secondary effects compared to business travel and does not necessarily generate wider economic impacts compared to business travel. Furthermore, air traffic volumes and destinations do not capture the onward connection flights created by hub-and-spoke networks, which are essentially the appropriate metrics for air connectivity and accessibility in empirical analysis. In the literature review below, we provide an idea of how to quantify network quality with several aspects that influence the network and how to ensure the "quality" is determined.

2.3.1 Connectivity

The starting point is Neal (2011), who states that cities occupying a central position in a network are more powerful. In this line of reasoning, centrality is often a driving force behind two processes: the concentration of resources in cities and the diffusion of resources throughout the network (Neal, 2011). For example, accumulating resources can make a location a centre for innovations, spreading throughout the network. The literature explains the concept of power in various ways. Neal (2011) mentions two important views for the Dutch case. Cities that can attract multinational corporate headquarters may be seen as powerful because of their influence on the global economy and the potential economic effects on the local economy (discussed later). Cities may also be seen as powerful when they dominate global supply chains (Neal, 2011). "Power" is derived from the city's position in a network. A well-connected city, "at the centre of several converging resource flows" (Neal, 2011) might be powerful.

Connectivity is related to "power" and can be used to measure centrality or power. It, thus, partially serves the purpose of a network quality indicator because a city (airport) with a high connectivity level connects to many other cities (airports) with good connections. Connectivity captures the quality of the network to overcome distance while ignoring the geographical locations (Graham et al., 2020): a "well-placed" city will have a high connectivity level. Connectivity is established by providing links between two points, routes and scheduled operations for public transportation, whereas private vehicles rely mostly on road infrastructure and availability. Since third parties provide air and rail transportation, the connectivity quality derives from the services offered. The physical infrastructure is necessary but insufficient to determine the network quality. Therefore, we regard connectivity as an aspatial approach. Specifically, connectivity measures the rate at which a network allows users to overcome distance without looking at the actual demand level or rationale to offer a specific link in the network. It is a measure of "how well are we connected?" and by relating this to a level of economic activity, we can establish if there is a close connection between connectivity and economic performance and how individual destinations influence this relation (Chapter 6).

An early study by Freeman (1978) suggested that connectivity relies on centrality measures and mentioned two indicators of centrality: degreeness and closeness. Degreeness is the number of directly connected airports, which is close to what the Ministry of I&W wants to achieve by considering direct connections. The degreeness of an airport can also be measured using the weight degreeness of direct-flight frequency to the national market share of the destination airport, also referred to as destination quality (Cristea, 2017). Note this already includes a volume indicator (frequency), which will be closely related to demand (or size of the destination). Closeness is the number of legs (stops) required to reach the destination. Closeness connectivity is measured by the steps necessary between a specific origin-destination pair. This indicator can be calculated as the number of destinations over the sum of the number of links between nodes in a network on the shortest path (Wang et al., 2011). To put this into perspective, an airport that scores high on degreeness and closeness provides travellers with direct connections to many other airports spread evenly without a focuss on specific airports (compare Neal et al., 2010). Note that this is a pure network indicator and does not say anything about the actual value (or quality) offered.

Cheung et al. (2020) use the following metrics that "are sufficient to cover most identifying characteristics of an air transport network":

- *The degree of an airport* describes the number of other nodes connected to the airport.
- *Flow Betweenness* describes an airport's original shortest-path betweenness centrality. It is defined as the relative fraction of the shortest paths passing through the airport in question. This metric assumes that travellers choose the shortest route for their trip. This assumption ignores some basic ideas behind airline networks, namely that airlines offer indirect flights to passengers, and passengers can choose such flights if lower fares offset the "penalty" of additional travel time. Note that other criteria, such as frequent flyer programs, influence the traveller's decision. The point is that the shortest path is not the only feasible alternative for passengers, and many airlines would fail if their passengers used only the shortest paths. But from a passenger perspective, it seems reasonable to assume that passengers will go for the alternative that yields the highest utility. Given fares (frequent flyer programs, etc.), the shortest path (flying time) seems reasonable. Therefore, This metric is not automatically consistent with actual airline behaviour but indicates what a utility-maximizing passenger would like to see.
- *Closeness* is the proximity of an airport to other airports. An airport with a higher measure of closeness allows passengers to reach destinations with fewer stopovers than other airports in the sample. This idea is important in hub location. A conveniently located hub will reduce travel distance and the number of stopovers compared to airports with a less convenient geographical location (assuming the necessary flights are available). This idea is also consistent with passengers preferring short travel times, in the sense that when a direct connection is not available, we still look for the shortest (cheapest) path.
- Eigenvector centrality measures the importance of an airport by considering the importance of the airports to which it is connected. This measure rests on the assumption that not all connections are of the same importance. A flight from Amsterdam to Groningen (if it is on offer) is less important to Amsterdam's position in the network than a flight to London or Paris because London and Paris themselves are important nodes in the network. This observation takes into account the idea that there may be preferential destinations.
- Regional importance considers within-region connectivity and link intensity to determine an airport's importance for its region. For an airport like Amsterdam Airport Schiphol, this seems less important unless we consider that i) it serves as a hub to an international alliance (that has other hubs within the same region) and ii) it is part of a larger transport network, that (also) involves rail connections.

Cheung et al. (2020) created a "Global Airport Connectivity Index (GACI)" using principal component analysis to combine the five indicators mentioned above into a single index. This metric gives the relative importance of an airport in the global air transport network. Using data for 2016, Amsterdam Airport Schiphol was in sixth place in the top 55 global airports, after Beijing Capital Airport, Paris Charles de Gaulle), Frankfurt, Los Angeles International Airport and Dubai International Airport. Cheung et al. (2020) point out that these metrics characterize airline networks, as already mentioned above. Therefore, the network quality indicator (GACI, or the degree, flow betweenness, etc.) describes what we see. Still, additional steps, such as a correlation analysis, are necessary to infer that a positive relation to economic or social development exists. Note that GACI (and the underlying indicators) and the quality indicator of I&W have similar components (for instance, direct connection capacity). In Chapter 5, we point out the important differences, and in Chapter 6, we test GACI.

2.3.2 Accessibility

The improvement of the transportation industry and declining general transport costs have contributed to globalisation and the economy (Hummels, 2007). An accessibility metric, measuring the ease of reaching destinations as a function of travel time, monetary costs, external costs, etc., can thus also be found in the generalized travel cost, which is the sum of the monetary and non-monetary costs. This fact is an important aspect because an airport with a high level of connectivity, as discussed in the previous subsection, may be home to airlines that benefit from the high level of connectivity by setting high prices: quality comes at a cost to passengers. In a very competitive market, this is unlikely, and airlines are happy if they can cover costs. But if there is market power, airlines can charge relatively high prices. A hub-spoke system may lead to hub-premiums (Lijesen et al., 2005). An implication is that some passengers find direct tickets too expensive and fly indirectly or not at all.

Furthermore, continuing the previous point, a well-connected airport will have a relatively large local environmental impact due to the many flights offered. The global environmental impact, particularly CO_2 emissions, also depends very much on the types of aircraft and the distances flown to the connecting airports. This effect aggravates if part of the local population chooses to fly indirectly. Thus, external costs need to be counted because they lead to welfare loss or may become part of the generalized travel cost. This analysis is not an easy exercise: allocating externalities from CO_2 emissions from international to the national levels in the country of the airport is subject to much discussion (Wood et al., 2010).

The approach by Arvis and Shepherd (2011) used the gravity model on flights to calibrate the accessibility metric. They estimate the generalized travel cost between origin and destination with a regression of direct flights and distance, accounting for a fixed minimum cost (Arvis & Shepherd, 2011). Each node's departure and destination potential is calculated as fixed effects in Poisson regression. The generalized travel cost of distance and potential node are then used to calculate accessibility. The gravity approach is common in the literature and assumes that two locations with high "mass" (population, GDP, etc.) will generate high trade or transport flows. Distance is an important impeding factor and often counts as part of the generalized costs. The effect of firm behaviour can also be an impeding factor. The firm offers transport services, but if prices are high, the firm will not meet part of the potential demand, and transport flows will be relatively low (although this can fit the firm's strategy perfectly).

A consequence of the gravity model is the so-called 'distance decay' (Luoma et al., 1993). Distance decay assumes an exponential reduction of the number of trips between two places as a function of the distance between these places. Mckercher and Lew (2003) explored distance decay in travel and found the simple exponential relationship more complicated. They conclude that market access, for which geographical, political and economic restrictions may limit, is the cause for the complexity. However, Peeters and Landré (2012) show for the Dutch holidaymaker that in (international) travel, it is not distance but travel time decay. It seems that the travel time decays, not the distance. Researchers did not see this initially because most transport systems for daily traffic have equivalent speeds.

However, when one includes the aircraft, a transport mode with a one-order of magnitude higher travel enters the equation. Increased transport speed implies that the physical distance plays a much smaller role in the distribution of trips, while the emissions are still directly related to the physical distance. This fact means that the CO_2 emissions are no longer driven by trade volume (the number of trips) alone but particularly by the speed of the network offered and the concomitant increase in distances. An important question is whether the economic value of trade is influenced by the physical distance or mainly by the travel time. Would it be possible to generate the same economic benefits with a 'slower' connectivity to the world? This question, and the whole idea of looking at accessibility, plays an important role in the policy discussion surrounding the "quality of the network". What do passengers want (travel time or speed vs. fare), what passengers do we include anyway in the analysis (tourism or business, and then: what business?), and finally, what do airlines do? A high-quality network allows airlines to set relatively high prices, which means some passengers will no longer (be able to) travel. On the other hand, a high-quality network is "expensive". In the sections on economic benefits and the methodology used by the ministry of infrastructure and environment we return to these points.

2.3.3 Airport Quality

Airport quality is crucial to measure the efficiency of transportation (Adler & Berechman, 2001). The efficiency of air transportation is one aspect of determining network quality. Berechman and Adler (1999) show that airport quality can be measured by amenities such as easy access, processing time, etc. With the rise in the importance of the hub-and-spoke model, airlines started to look into demand and network factors of location (centrality). An airport with a high degree of location and centrality could attract more routes and create hubbing opportunities for airlines (Song & Yeo, 2017). The airline decides to use a hub-spoke type operation (or is captive, based on a historical decision). However, recent developments, such as easyJet offering intercontinental destinations using partners' networks, show that airport quality allows airlines to expand their strategy and portfolio. easyJet did not offer such destinations in the past but uses the opportunities they see at airports. (Parker, 1999) measured airport quality from the airlines' point of view. Objectivity and subjective assessment from the airlines are becoming more important for an airport to understand which improvements their clients need. All-in-all, a "high-quality network", however we define this or measure this, requires a high-quality airport. In practice, we have seen this at Amsterdam Airport Schiphol, which has won numerous awards over the years. But, as mentioned already in the previous subsection, high quality comes at a cost, so the question remains: for whom are we doing this, and what is the economic benefit? We return to this when we discuss economic benefits.

2.3.4 Air Service Quality

Stamolampros and Korfiatis (2019) show the direct connections between airline service quality and air travel demand. The service quality stimulates the growth of passenger numbers, networks and destinations. As the airline industry provides the ground for economic development, global trade, tourism and investment, it is only necessary to maintain the demand and passenger satisfaction. But there is the problem that high quality of direct and indirect connections, for example, measured in frequency, boosts demand and therefore emissions of CO2, noise and other pollutants (which are discussed further in Section 4), so that the network scores less on different aspects related that are also associated with quality (for example wellbeing). Tahanisaz and Shokuhyar (2020) argue that one should segment customers based on their expectations to determine their service satisfaction. For instance, business passengers have different requirements compared to leisure passengers. Suppose the network and its various components are of good quality (for example, a relatively large number of direct connections). In that case, passengers may be relatively highly willing to pay for the service. Therefore, economic benefits (measured as the net benefit in the market) may increase because of the high willingness-to-pay (Section 3). On the other hand, airlines can charge higher fares for a high-quality service. Carlos Martín et al. (2008) regard the quality attributes of airline service as part of network quality. Higher service quality of airlines attracts passengers with a relatively high willingness to pay, such as business passengers. Let's take into account that business activities are crucial for the economy. A high quality of service in the air transport industry induces the travellers' confidence and the passengers' demand. Passenger perception of service quality includes cleanliness, comfort, food, in-flight entertainment and the appearance of the crew, but assurance consistently ranks as the most important attribute (Gilbert & Wong, 2003). Business travellers are more price-sensitive passengers who will choose not to fly directly. We return to this in Section 3.

2.4 Conclusion

Air service and airport quality are important because connectivity measures do not depend on passenger preferences, attitude towards quality, or willingness to pay for air services. Accessibility metrics derive from the generalized travel cost. These include monetary and non-monetary costs and (also) depend on the quality of the alternatives offered. After all, passengers are relatively highly willing to pay for high-quality services if airports and airlines focus on the correct quality attributes. One important reason to look at network quality, in general, is the expectation that a high-quality network will have significant economic effects, in the sense that a network with significantly higher quality than other networks results in significantly higher economic benefits, again compared to other networks. The reason for this is that "quality" attracts passengers with a high willingness to pay, and thus, benefits are relatively large (Bel & Fageda, 2008; Brueckner, 2003; Button et al., 1999); also see next chapter. The benefit, therefore, is not considered as part of the network and nodal quality but as a potential result of the network and nodal quality. In the next Chapter, we discuss economic effects, and part of the discussion focuses on direct and indirect effects that can be determined from inverse demand functions that give consumers a willingness to pay for travel alternatives. Thus, the discussion of network quality in this section and their influence on willingness-to-pay carry over to the next section. This discussion implies that we see network quality as a measure that describes how well one point in a network connects to the other points in the network. Of course, there are different ways to do this (connectivity, accessibility, etc.). At a macro level, when the policy objective is to stimulate a national economy by linking "the economy" to the rest of the world, the question is if a high level of connectivity means we score high on the economic indicator related to the objective to the network or policy (in the sense that we see high correlation). At a more micro level, the behaviour of the airlines and airports comes into play. We can determine how airline or airport behaviour affects the network, nodal quality and "the economy". Key points then are: i) how to measure the "economic effect" (this is discussed in Chapter 3 and studied in detail in Chapter 5); and ii) do we focus on a macro or micro level (in other words: do we use a measure that is dependent on firm behaviour)? Any debate on which destination to include in the metric becomes irrelevant if the metric considers the complete network under consideration.

Furthermore, such an indicator is useful to say something about current (policy) issues, for example, the discussion of downsizing airports. What is the impact of a reduction of x% of the flights from Schiphol on the economic benefits of the network? Such a reduction may impact network quality and potential economic effects. Chapter 5 describes this, but first, we discuss the economic effects and the methodology from the Ministry of Infrastructure and Water Management in the next two chapters.

3 Economic Effects

Objective

"Network quality indicates the extent to which the Netherlands connects to the rest of the world" (Ministerie van Infrastructuur en Waterstaat, 2022b, p. 1), Still, of course, the connections themselves also serve a purpose. Earlier, I&W observed that air connectivity serves three main purposes: improving the business climate, the competitive position of the Dutch economy and the well-being of Dutch travellers (Ministerie van Infrastructuur en Waterstaat, 2020). This chapter starts from this view and looks at the measurement of economic benefits and how they depend on firm behaviour. It includes direct economic effects (related to the direct added value of the aviation sector) and indirect effects related to impacts on the Dutch economy enabled by air transport but generated in other sectors.

Key findings

- Basic (and common) findings are that: i) the literature points out positive economic effects of aviation; ii) some studies look at the causality of the relation; and iii) various indicators (GDP, employment, direct and indirect economic effects, etc.) are used.
- In a theoretical framework, the direct effect measures the increase in net surplus in the transport market.
- Because transport is an input, the direct effect will be passed on to the final users as the indirect effect. In a perfectly competitive market, the direct effect will be perfectly passed on to the final consumers (the indirect effect). An additional indirect effect over the direct effect, we would, in fact, be double counting.
- This conclusion changes in case of market failure, such as market power or scale effects underlying airline strategies. There is a positive additional indirect effect (over the direct effect) if the transport company prices above marginal costs (Rouwendal, 2012).
- Because aviation markets are, to a large extent, international markets, benefits of indirect travellers mostly accrue at the origin or destination (and likely not at the transfer airport).
- The findings above imply that an analysis of network quality must precisely define which economic effects are important and where they come from (both in a locational sense and a theoretical sense considering market power).

3.1 Introduction

Many see air transport as an important driver of the local economy. The underlying idea is that a high-quality network serving many of the most relevant cities would be competitive with networks offered by other international airports and contribute to the national economy. This idea also played a role in policy discussions, such as the preferred destinations surrounding the Air France-KLM alliance. The literature supports the idea that aviation services may indeed have economic benefits. For example, Adler and Berechman (2001) find that air transport is a means for overcoming (very long) distances in a globalising world. The possibility of using infrastructure and transportation services widens the opportunity for interaction (Allroggen & Malina, 2014), benefitting the economy (Lakshmanan, 2011). However, the concept of network quality does not automatically imply that all long-distance destinations equally contribute to a local economy. If the purpose of a quality indicator is to measure the contribution to a local economy, it is not just the distance or service level that counts. The RLI (2019) argues that many look at network quality from the perspective of the number of connections (cities served) and frequency of service. As such, it often serves as a measure of the competitiveness of the airport in question. According to the RLI (2019), the economic value of specific destinations receives too little attention: what connections (cities served) are important to the local economy? Therefore, the RLI (2019) proposes to consider how many and which connections are vital to the Dutch economy. The Ministry of Infrastructure and Environment aims to achieve this by using a network quality indicator that considers the availability of direct connections to preferential destinations (Ministerie van Infrastructuur en Waterstaat, 2022b). Preferential destinations are those considered economically important, measured using the Globalization and World Cities-index (GaWC), and have strong cultural ties to the Netherlands.[4] While this "new" indicator includes the economic value of the destinations, and therefore apparently addresses this particular issue raised by the RLI (2019), the question remains if the new methodology really determines the network quality, in the sense that "the network significantly contributes to the economy". Therefore, this chapter addresses the question of how to measure "economic effects", and indirectly if the GaWC-based indicator is the correct network quality indicator. This is done by providing a literature review with a focus on i) airline behaviour; and ii) how to measure economic effects. While the proposed network quality indicator does not aim to say anything about airline behaviour, the destinations served and associated frequencies and fares are decided upon by the airline. Thus, airline behaviour will impact any indicator based on the number of destinations or frequency level, and economic benefits are associated with the willingness to pay, which determines airline fares. Neglecting the impact of airline behaviour can, therefore, result in a biased indicator.

3.2 Economic effects: basic findings

Looking at economic effects is strongly related to the airport's position in an airline's network. The RLI (2019) already mentions that Dutch aviation policy strongly focuses on transfer traffic and the hub function of Amsterdam Airport Schiphol. In 1997, Amsterdam Airport Schiphol reported that only four major hubs would remain in Europe (Amsterdam Schiphol Airport et al., 1997), and tough competition for a hub position was expected. "Having a hub" would be beneficial to the local economy (Bel & Fageda, 2008; Brueckner, 2003; Button et al., 1999), and losing a hub as a result of competition (O'Connell, 2011) could lead to (and, in specific cases, resulted in) dehubbing (Redondi et al., 2012; Wei & Grubesic, 2015). Dehubbing of airports could lead to the loss of economic activity in the region surrounding the airport (Bilotkach, 2015). In the case of dehubbing, low-cost airlines could replace the hubbing carrier, but such airlines hardly serve intercontinental destinations, and Budd et al. (2014) report a 77% failure rate of low-cost airlines. Budd et al. (2014) report that low-cost carriers with a small scale of operation (measured in resources, fleet size and network size) are more likely to fail and also point out that routes with sufficient demand to sustain long-term operations are necessary to remain successful. Essentially, having a hub in the region is beneficial to the local air carriers, which minimises their operational

[4] Note that thinking in terms of "preferential destinations" is not new. This also played a role when the alliance between Air France and KLM was formed, and the years following the formation Air France-KLM.

costs, but to what extent can the hub contribute to the economy? However, because routes are offered in the long term when there is sufficient demand, and noting that demand for aviation services is derived demand, the "quality" of the destinations served ("economic strength") seem to be important drivers of airline success and, as a result, the potential effect on the surrounding economy. This means that policies, or at least the network indicators used to make policy, were, to a large extent, based on the networks offered by airlines. A wide range of (high quality) destinations could be served (with high quality service), only because of the airline business model used at the airport.[5] So while the RLI (2019) mentions that Dutch aviation policy had a strong focus on transfer traffic and the hub function, this follows from policy objectives that particularly support a certain airline's interests, rather than the broader Dutch economy or society. This policy enabled this airline to serve a large number of destinations. The policies are based on the airline strategies of the past few decades because the network observed followed from airline strategies.

Most of the air transport industry's economic analyses focus on air services' impact. For example, (Button & Yuan, 2013) suggest that air freight helps foster economic development. Passenger air transport significantly increases employment (Brueckner, 2003). Sellner and Nagl (2010) also suggested that air accessibility directly affects GDP and several indirect effects, such as increased regional investment. Tolcha et al. (2020) found causality from economic growth to aviation growth except for one country, where the relationship was from aviation growth to induce economic growth.

Market access describes the easy interaction between market and economic opportunities (Redding & Schott, 2003), and in this sense, connectivity is good for the economy. Researchers can determine an air network's economic effect by the business activities and tourism it facilitates. Air connectivity increases the attractiveness of the local region to foreign investments and promotes economic growth (Bannò & Redondi, 2014). Air services to various destinations facilitate face-to-face contact between businesses, stimulating employment and establishing enterprises (Brueckner, 2003). The increased air traffic contributed to increased GDP employment rates in certain regions directly and indirectly (Allroggen et al., 2013; Zhang & Graham, 2020). The expansion of low-cost carriers also helps serve the secondary cities of the regions that influence tourism activities (Dobruszkes, 2013).

3.3 Measuring benefits

From the discussion above, we can conclude that i) the literature points out the positive economic effects of aviation, ii) some studies look at the causality of the relation, and iii) various indicators (GDP, employment, indirect effects, etc.) are used. It has become common practice to describe the economic effects in terms of direct and indirect effects. ATAG (2018) defines direct effects as "the employment and activity within the air transport industry", and indirect effects as "employment and activities of suppliers to the air transport industry". ATAG (2018) also mentions induced impacts, "spending by those directly or indirectly employed in the air transport sector", and says that catalytic or induced effects are by far the "most far-reaching economic contribution". While such induced effects appear in the literature occasionally, the theoretical foundation is often weak. The key point is that indirect effects are absent if all markets under consideration are perfectly competitive. The reason is that the spending of a direct effect automatically becomes a cost item, and these cost items cancel out unless the market is not in perfect competition. Rouwendal (2012) illustrates this by looking at the effects of an investment in infrastructure. The investment causes a price reduction in transportation (after all, capacity is less scarce) and an increasing surplus in the transport market (call this the direct effect). Transport is an input, and in a perfectly competitive transport market, the benefit (the direct effect) is passed on to the final users. Call this reallocation of the direct effect the indirect effect.[6] In a perfectly competitive market, a cost advantage (the direct effect) will

[5] There is a large number of papers showing why a hub-spoke network is optimal, given cost and demand parameters. Relatively recent developments show that low-cost airlines usually use point-to-point networks, but most of these still fly relatively short distances.

[6] Direct and indirect effects are key to the necessary cost-benefit analysis that is necessary in the Netherlands when infrastructure investments are planned.

be completely passed on to the final consumers (the indirect effect). If we include an additional indirect effect over the direct effect, we would be double counting because the "true" indirect effect is the same as the direct effect. This conclusion changes if transport companies have market power. In that case, an infrastructure investment changes the input and output prices. There is a positive additional indirect effect (over the direct effect) if the transport company prices above marginal costs (Rouwendal, 2012).

This theoretical discussion is relevant for two reasons. Firstly, positive additional indirect effects (so on top of the direct effect) result from market failure. The fear of dehubbing is associated with the fear of losing the direct and indirect effects of the hub-spoke operation. Hub-spoke networks are important because there are economies of density. So, there is market failure, and likely, there are indirect effects. A high-quality network may give rise to large indirect effects to be established from empirical research. But if this is a hub-spoke network, then the economic (indirect effect), to a large extent, is the result of market failure. From a policy perspective, this at least needs some consideration. From an economic perspective, the question is if investment in the hub is the best way to obtain the indirect effect or to deal with market failure. In other words, the network indicator may indicate a high-quality network, but could the indirect effects have been obtained in any other way not involving market failure?

Secondly, direct and indirect effects may be experienced in international hub-spoke networks at specific locations. An additional indirect effect in the market between Dubai and Trondheim may exist, but should it be counted for Dubai, Trondheim, or the hubs used to serve this market? The latter would be odd because the benefit of having a hub is already counted in the cost (by exploiting scale effects). The indirect effect in this specific output market is the result of travellers between Trondheim and Dubai benefitting from the infrastructure. Those effects accrue to the travellers from Trondheim or Dubai. While the proposed methodology to measure network quality as proposed by the Ministry (see Chapter 5) does not aim to target business travellers specifically and does not support the hub-spoke model or individual carriers, the current network is still, to a large extent, the result of a hub-spoke operation. Connections to cities that score high on the chosen index will (also) generate indirect traffic so that the argument above remains relevant. To put this argument into perspective, Neal (2010) reports that only a percentage of travellers arriving in a hub city remain in that city (30% in the case of Cincinnati, almost 56% in the case of Chicago, other cities with a hub show a percentage in between). The remaining travellers arrive at the hub only to connect to another flight.

Using data from 2006, Neal (2010) finds that centrality in the hub/spoke network had a strong positive effect on employment in aviation-related jobs, while it has an insignificant effect on employment in non-aviation jobs. On the other hand, origin/destination network centrality had a robust positive effect on employment in non-aviation jobs. In contrast, it had a slightly negative effect on employment in aviation-related jobs. According to Neal (2010), these findings support the idea that analysis of origin/destination networks is more appropriate for studies of advanced urban economies than analyses of hub/spoke networks, which are appropriate for studies focusing on the airline industry. These findings depend, of course, on the fact that U.S. data are used. In that setting, a city like New York may be less important as a hub but more important as a major city with a high level of "power" (see 2.2.1 for a discussion of "power").

In the European case, or specifically, in the case of Amsterdam Airport Schiphol, where a hub-spoke system is used for the same reasons (to exploit density economies), although its history is somewhat different (KLM was a flag carrier that operated a hub-spoke-like network before we called it a hub-spoke network), the outcome of a similar regression might be different. But the key point remains: travellers that transfer via the hub are important to the economy at the origin and destination (where the benefits accrue). They are also important for the direct economy at the hub (because they create jobs at the airline, airport, and suppliers) and indirectly because they contribute to lower average costs, also for OD passengers, so that the hubbing airline can offer an extensive network. The benefit of that network to the local economy derives from passengers that use the hub as their origin or destination. The size of that effect depends on how much of the reduction in average cost (due to the presence of indirect travellers) passes on to local OD passengers and the pricing strategy of the hubbing airline. In a competitive market, prices will be lower, but direct flights can get expensive due to (airport or seating) capacity scarcity, and in case the airline has the power to charge a hub-premium or both. For example, a business traveller from Oslo or Trondheim to Dubai taking an indirect flight may be more valuable to the airline than a passenger flying directly on either of these links. Therefore, the local effect to the consumer, which drives the economic effects discussed above, may be smaller than expected.

As already mentioned above, the network quality indicator proposed by the Ministry (see Chapter 5) does not aim to target business travellers specifically nor to support the hub-spoke model or individual carriers. But it incorporates "preferential destinations" and seats offered so that at least components of airline business models (including the potentially high OD-fares, see 2.3.2) still drive network quality indicators. After all, airlines fly to cities when there is enough demand (direct and indirect)[7]. They base the number of seats on network considerations, not necessarily direct OD demand. Therefore, indirect travel may be necessary to offer a large number of destinations, and this may result in a high network quality indicator (for example, high connectivity). Still, the direct effect may be less than a point-to-point network because the direct effects of indirect travellers accrue elsewhere and the indirect effects, if they exceed the direct effects, result from market failure. This market failure makes it all the more important to relate network quality to economic effects because it is not straightforward that high network quality (resulting from hub-spoke operations, if established) automatically leads to the highest (direct) effects.

[7] Next to that some airlines may serve cities because they are the designated carrier in aviation treaties.

4 Environmental Effects on Network Quality

Objective

In the current line of reasoning, network quality focuses on the exogenous added value to the Netherlands of individual destinations. However, this reasoning ignores negative externalities. This chapter aims to review the literature on the environmental implications of network design. The reason is that different network configurations (and associated costs) may achieve equal benefits ("revenues") from specific destinations.

Key findings

- The literature points out that "hubbing" negatively affects the environment compared to a point-to-point network.
- The overarching economic goals of the Ministry of I&W necessitate ncluding externalities because network choices like size, distances to connections, and types of aircraft and transport modes used have significant impacts on the net economic effects.

The aviation industry is one of the contributors to social and economic development at global and national scales. At the same time, aviation's environmental risks have increased, not only in terms of local air quality and noise but increasingly in emissions such as CO_2 and non-CO_2 effects like NO_x and the formation of contrails and cirrus clouds that can cause global warming and climate change. The Ministry of I&W explicitly excludes these effects from their indicator because they feel it does not say anything about the network. We argue that ignoring these effects, which affect the economic and well-being goals proposed by the ministry, renders the indicator incomplete. With the growing environmental risks in aviation's future growth in traffic, there is a substantial need to understand the feasibility and cost of controlling the risks while maintaining the social and economic benefit (Morris et al., 2009). Some emissions have an impact on land and water quality, some have effects on local air quality, and other effects impact on global atmosphere. Regulatory authorities are mostly concerned with the emission of Hydrocarbon (HC), nitrogen oxides (NOx), carbon monoxide (CO), smoke, particular matter (PM) and noise, especially for controlling local air and environmental quality (Steve et al., 2015; Tesseraux, 2004). On the global scale, CO2 emissions are mostly the concern for its global warming potential. However, in aviation, the non-CO_2 effects on the temperature rise historically are twice as large as those from all accumulated CO_2 emissions from aviation (Lee et al., 2020). The network quality indicator of the Ministry does not take the environmental performance of the network into account. Because network configurations have different emission patterns and levels of external costs, a network quality indicator that looks at economic benefits while neglecting external costs may lead to a biased conclusion.

To further develop this point, we must first realize that the literature points out that the environmental performance of different network settings varies significantly (Peeters et al., 1999). Deregulation has encouraged the expansion of air transport in terms of the number of airlines, routes, and frequency, as well as the creation of a hub-and-spoke operating model. With early studies showing a direct link between environmental impact and engine combustion, number and duration of flights, we could see that deregulation and the associated move towards hub-spoke systems and demand growth could have a significant impact on the environment (Daniels & Bach, 1976; Nero & Black, 1998; O'Kelly, 2014; O'Kelly, 2012). A recent study by Sun et al. (2021) shows that the adoption of hub-and-spoke networks by airlines induced an increase in the environmental impact by a factor of 2.81. Hence, the environmental external cost is higher than in the city-to-city networks. Their results were in line with the arguments of Schipper & Rietveld (1997) and (Peeters et al., 1999) that deregulation in the aviation sector promotes the expansion of air traffic and creation of hubs and increases the overall environmental impact. The hub-and-spoke network reduces an airline's operating costs by centralising operations but has a significantly higher impact on the local environment than a non-hub airport (Peeters et al., 1999). In the discussion about the quality of the air transport network and the measurement of the net benefits of the network, a network quality indicator may relate network connectivity to economic benefits. But as discussed above, the benefits of international networks may accrue at different places for different network configurations. And on top of that, different network configurations lead to different levels of external costs, so that the actual "local" net economic benefit of a specific network type is not necessarily the highest for a network with the highest level of connectivity according to an indicator that ignores environmental cost. Policymakers thus must consider the economic benefit in relation to the environmental impact that it carries.

Likely, environmental policy will become the fundamental constraint on air transport growth. Improvement in technology leads to more efficient engines, and airlines strive to maximize load factors, reducing the environmental impacts per flight. However, these efficiency improvements also reduce the cost of flying, increasing growth above the contemporary decrease of the cost of flying. Therefore, growth will outpace any technological developments to reduce the environmental impact. Aviation has a relatively strong rebound effect of efficiencies as these also cause large price reductions.

To have an in-depth understanding of the quality of the network, an approach regarding the net benefit of the air transport network is essential. The expansion of the aviation industry induces economic growth and has positive effects but simultaneously increases environmental externalities. Considering both aspects in the study could capture the fundamental understanding of the network quality framework. A quality indicator including seat capacity to "preferential destinations" essentially describes what airlines offer as seat capacity between the destinations via the hub. Though the Ministry does not intend to let the quality indicator support the hub idea, as argued above (chapter 3), the indicator may indirectly still do so. This chapter has shown that economic effects ignoring externalities are not a good way to assess the overall economic impacts.

Furthermore, the literature points out that "hubbing" negatively affects the environment, compared to a point-to-point network, so the economic benefits of hubbing correction for the externalities. If the home market is relatively small, a hub-spoke network is necessary to offer (a large number of) long-distance destinations. Flights to these destinations are responsible for a large part of the CO_2 emissions caused by aviation. Thus, the network quality indicator should not support the hubbing idea. However, we believe it supports the hub via the seating capacity, which is likely larger in a hub-spoke setting than in a point-to-point network (Brueckner & Zhang, 2001). This fact indicates the proposed quality indicator ignores the environmental performance of the network. We return to this point in Chapter 6.

5 The NQI proposed by the Dutch government and a proposal for a different indicator

Objective

The objective of this chapter is to use the insights from the previous chapters to form an opinion on the proposed NQI. Furthermore, the chapter suggests to develop an alternative indicator.

Key findings

- The quality indicator does not aim to indicate hub performance, but using selected cities and the number of seats, it likely represents hub performance.
- The quality indicator does not aim to describe airline behaviour, but its components are still dependent on airline behaviour (network setting, pricing) and externalities.
- Selecting destinations important to specific sectors means other ectors are less important or even ignored.
- The proposed different network indicator does not a priori select estinations, considers network connectivity (to consider how the Netherlands connects to the rest of the world), considers environmental effects, and extends to different modes.
- If the indicator strongly correlates to a social/economic indicator, the network is of high quality because it contributes to policy goals (focussed on the social/economic indicator).
- Indirect connections may be included, considering limits to the onnection's quality, such as a maximum of two transfers and a maximum of 6 hours of transfer waiting time.

The Globalization and World Cities-index (GaWC) is used to form an objective view of important destinations. The 2020 version contains hundreds of cities, weighted based on the presence of listed companies active in the following sectors: business services, law and accountancy, banks, publicity and consultancy. The Ministerie van Infrastructuur en Waterstaat (2022b) applies a GaWC list dedicated to the Netherlands created by Ben DeRudder from Leuven University (DeRudder, 2021). The presence of headquarters gives a higher weight. While this idea is in line with the concept of power discussed earlier, it seems there is a high degree of sample selection: the Ministry chooses the important destinations considering specific sectors and then proceeds by saying we have a high-quality network if we have connections to these destinations. However, the selected sectors are not the only ones that generate potential demand or benefit from the supply, so there also is a selection effect. One could argue that the abovementioned sectors bring a lot of value. Still, the question is where this value accrues, given the international nature of many firms active in these sectors. As discussed above in Chapter 3, a hub-spoke network depends on indirect travel, and the benefits of indirect travellers most likely accrue elsewhere. The benefits of origin-destination travellers are more likely to benefit the local economy, but since we are selecting international firms, this is not a certainty. For the airlines, indirect travellers are necessary to sustain the larger network and, thus, a higher turn-over.
The network quality indicator (NQI) depends on the GaWC of the destination city served by the airport and the number of seats between AMS and the city. Current operational strategies for the most important airlines at the airport still depend on indirect travel to fill seats, and sometimes indirect travellers are, for the airline, higher yielding than passengers in OD markets. Whereas some airlines operating from the airport offer seats to passengers who do not have the airport as the origin or destination, other airlines offer seats to passengers who have the airport as the origin or destination and transfer elsewhere to reach the final destination (for example, a

passenger flying via London, Dubai or Reykjavik to the final destination[8]). Such passengers contribute to the local economy here, maybe even more so than passengers transferring here. *So, while the quality indicator does not aim to be an indicator of hub performance, a network quality indicator that includes selected cities and the number of seats and ignores further airline behaviour (network setting (chapters 2 and 3), pricing (chapters 2 and 3), externalities (chapter 4)) does not paint a complete picture.* Competition is fierce in indirect markets, leading to growth in passenger numbers because of the lower fares for indirect flights) and in passenger kilometres (because of the growth of the number of flights and the detours indirect flights make). As mentioned above, the literature suggests that "hubbing" has a significant additional environmental impact.

Finally, firms compete for potential employees in a tight labour market. The same holds for other scarce resources. Selecting and (indirectly) stimulating certain sub-sectors may have long-run effects within and outside the transport sector and sectors under consideration. For example, railways or high-tech firms compete for the same skilled employees now working at the aviation hub, hampering the environmentally important shift towards more rail travel and the energy transition. The long-run economic impacts of the effect of a high score on the proposed network quality indicator cities, attracting international headquarters of, for example, banks, might not be as positive as it seems. Also, it may hamper railways, which generally score much better on environmental parameters and internationally compete directly with airlines. Employee and capacity shortages recently seriously impaired international rail travel from the Netherlands. Compare Neal (2010), who finds that centrality in the hub/spoke network had a strong positive effect on employment in aviation-related jobs, while it has an insignificant impact on employment in non-aviation jobs. Based on this finding, we can hypothesize that if we select sectors that benefit from the aviation sector and cities that are "big" in these sectors, we will find that a network linking these cities will be important and the network will be good. Other sectors that compete in the labour market for scarce workers are less likely to benefit, and cities "big" in other sectors will be deemed less important. The choice for an indicator favouring cities that score high on a particular metric (GaWC in this case) may also favour the airlines that fly to these cities and the sectors the score is based on. Furthermore, in a cost-benefit analysis[9], it may be very hard to determine the direct and indirect effects of adding or dropping a destination from the network. The reason is that any destination links to many other airports via the hub. Above, we argued that we derive most of the benefits from OD passengers, but determining this direct effect depends on the prices charged, which, in turn, depend on airline pricing decisions throughout the network.

For these reasons, we advocate to develop a network indicator that describes the complete network. That network is not limited to preferential destinations because the researcher or policy maker selects which cities are important, a difficult-to-objectivise endeavour and often biased towards certain subsectors or interests. On a macro scale, when the policy objective is to stimulate a national economy by linking "the economy" to the rest of the world, the question is if a high level of connectivity to the rest of the world means we score high on the economic indicator chosen by the policy maker. Note that we can still determine the effect of dropping some destinations (see Chapter 6). Therefore, the suggestion is to develop a new indicator, an International Connectivity Impact Indicator (ICII), based on the following

(Chapter 6 will explore some of the indicators mentioned below):

- Take the economic/social network revealed by current outbound and inbound travel behaviour as a starting point for the network (do not select "important cities"). If there is no direct connection to another city, there still may be an indirect connection. The connectivity index described below will be relatively low if there is no indirect connection.
- Describe the network using a connectivity index. The GACI-index described above in 2.3.1, or any of its components is an option. The results from the data analysis will reveal which connectivity index

[8] Note: this relates back to the concept of connectivity. A link to another airport that is very well connected adds to connectivity, even if the city in which the other airport is located is not "big". From a policy perspective a connection to this airport may be less important because the city is small, but using the same argument,

[9] Cost-benefit analysis is required when an investment in infrastructure capacity is made. When infrastructure capacity is downsized similar arguments (for doing a cost-benefit analysis) can be used. This essentially is also what the network quality indicator tries to indicate: what is the added effect of a destination.

is the most appropriate (see Chapter 6). For instance, the GACI index is created using principal component analysis to combine the five basic indicators mentioned above into one index. The empirical analysis reveals which indicator plays the biggest role in the GACI indicator, which is case-specific (see 2.3.1).

- Another option could be to look at the indirect connections by setting certain limits to the quality of the connection. Such quality limits might be a maximum of two transfers and 6 hours of transfer waiting time. The OAG airport connectivity analyser is potentially a good tool to do this. The quality indicator would then be a combination of the quality of the connection in terms of travel time and transfers and the quantity of all direct and indirect connections above a minimum quality.
- Be clear on the economic and social effects that are important. This choice is largely a political discussion: which indicators are important? In the current system, it is the sectors underlying the GACI-index, but other sectors demand labour and other resources. The choice of effects is often based on a plan for changing network size or infrastructure capacity, which forms the starting point of many cost-benefit analyses. In a cost-benefit analysis, difficult decisions need to be made: how do we determine direct and indirect economic effects, for what markets, etc. In trade, exports may weigh higher than imports. Inbound leisure trips contribute differently from outbound leisure trips because inbound leisure travellers "spend money here, " adding to local benefits. Note that, next to common indicators like FDI, GDP, etc., one can also consider indicators of local well-being. For example, Eagle et al. (2010) considered an index measuring relative prosperity based on income, employment, education, health, housing and environmental quality. Using such an indicator would make sure that the analysis is not limited to specific sectors (and they will be important anyway if that appears from the data) because aviation can have an impact on many other sectors and indicators: international students arrive because flights are offered, crowding out was already mentioned, etc.
- Determine the correlation coefficient between the network quality and economic/social indexes. In the next chapter, several probability plots (Lorenz curves, to be precise) plotting the two cumulative distribution functions of network and economic indicators against each other. If the cumulative distributions are similar, the resulting curve will be nearly a straight line; see next chapter and next bullet point.
- Suppose there is some correlation between economic/social indexes and network quality (or connection volumes). In that case, the next important question is how to change the network to minimize the reduction of the economic/social index of the network for a given reduction in volume/network quality. This question means one needs to consider two relationships: the effect of the change in volume per connection on the change in network quality and the effect of the change in network quality on the change in the socio-economic indicator, i.e. total spending of the traveller in the Dutch economy. If the Lorenz curve described above is (nearly) a straight line, all destinations "are equal" in their contribution to the network and economic indicators, so there are no "preferential destinations". But if there is a strong deviation from a straight line, some destinations do not matter that much, while others contribute, relatively speaking, a lot to the chosen indicators. These latter destinations would then compare to what the ministry sees as preferential destinations, albeit the data determines which destinations are preferential.
- Take into consideration the environmental impact of aviation. If the network quality indicators positively impact the economy, the next step is to determine the environmental impact. A connectivity indicator based on the shortest path is usually based on cost or geographical distance. A similar indicator could be drafted for environmental cost by using data on emissions for various aircraft. Alternatively, an existing connectivity indicator (second bullet point above) could be updated by including external costs.
- Also, consider the international rail connections network because the quality (speed, frequency) of international rail connections varies greatly. Transport by other modes than air transport needs to be taken on board because, for the economy, the displacement of a person or good has a certain value, which is not a function of the transport mode. Furthermore, we weighted the economic impacts of different kinds of travellers (inbound, outbound or transfer). This weighing follows from i) the discussion that aviation still serves a lot of indirect travellers, and the benefits derived from those travellers accrue elsewhere, as discussed above, and ii) when the policy objective is to stimulate a national economy by linking "the economy" to the rest of the world, then ignoring

destinations nearby or destinations that other modes can reach creates a large bias. Ultimately, the purpose is to stimulate the economy, not a specific sector.

- Carefully select a quality indicator that includes OD passengers for leisure, both outbound and inbound. The current index includes the interest of individual companies (airlines, airports) and the financial and high-level consultancy business travellers. At the same time, it ignores the normal or technical business travellers, the travellers for science and education and all leisure and VFR (visiting Friends and Relatives) OD passengers. These travellers may choose similar destinations, but the choice for specific destinations and industries precludes destinations that may have value for other types of travellers.

This system may be sufficient for policy-making and prediction of network configurations. Still, it is insufficient to explain how networks evolve or why airlines make certain decisions (on frequencies, routes, destinations, fares etc.). But that may not be the purpose of an indicator. Chapter 6 explores some alternatives.

6 Data-modelling results

Objective

The objective of this chapter is threefold: to reveal whether the GaWC-based network quality indicator has a relationship with the economic value of the network, to compare the I&W proposed indicator with some alternative indicators, and to explore a way to determine which connections add most and which ones add least to the Dutch economy in an attempt to help reduce the number of flights in the economically most efficient way.

Key findings

- The GaWC index for all indicators has a weak relationship with the current number of direct flights from AMS.
- The I&W proposed indicator NQI_{GaWC} cannot distinguish between direct destinations with a high or a low contribution to the overall NQI_{GaWC}. This failure means that adding 1% of randomly chosen destinations to the network will generally add 1% to the indicator. The indicator is, therefore, not helpful to determine or guide the growth or de-growth of AMS.
- Adding rail connections increases NQI_{GaWC} by 47% and causes the relationships between economic revenues and the number of connections to become positively correlated, while this is for flights from AMS hardly the case.
- Externalities for aviation GHG emissions reduce direct revenues from flights by 26%.
- NQI_{GaWC} hardly correlates to the direct revenues of international travellers to the Dutch economy, with or without correction for the climate effect.
- A Lorenz plot of total direct revenues corrected for climate impacts to flights from AMS reveals that 30% of flights with the lowest net revenues add nothing to the overall revenues.
- Trade balance and volume do not show a strong relationship with the network at Schiphol or the wider international network; therefore, trade is not a suitable indicator for the economic impact of the AMS network.
- The GACI (Global Aviation Connectivity Index) has no clear relationship with the number of flights. Therefore, GACI is not a suitable indicator for AMS network quality if the network quality should be a proxy for the economic value for the Netherlands and there is a clear relation between number of flights and the economic value.
- Alternative network quality indicators like Betweenness and Degree Centrality show a positive relationship with the number of flights (including transfers) but not for the total travel volumes of O/D-travellers (excluding transfers). This finding shows that these two indicators represent the pure network quality but do not relate to the real travel by air, making them less promising for further application.

6.1 Introduction

Current air travel databases provide passengers and flights from all five Dutch international airports to each other airport served. This provides a good starting point for assessing where passenger flows by air transport are located. The economic value of connections is determined through different parameters. The first are the direct impacts, translated to what a passenger arriving at or travelling out of a Dutch airport spends in the Dutch economy. The amount of spending varies to a high degree with the main type of passenger: outbound (e.g. Dutch holidaymakers), inbound (foreign tourists and business travellers visiting the Netherlands) and transfer passengers (those using Schiphol to transfer between flights related to trips starting and ending outside the Netherlands).

Furthermore, we want to add international travellers using modes like car and train because there are significant differences between the environmental impacts of various transport modes (EEA, 2020). Furthermore, the positive economic effects need to be reduced by the externalities to balance economic with environmental goals. Such data are unavailable in the air passenger databases.

So, we started with the aviation data and determined the flows to over 250 airports served directly by Dutch airports. Then we added travellers from three surveys describing holidaymakers, inbound leisure tourists and business travellers. These databases provide these data at the country and for the most important countries (like Germany, the UK, France, and the US) at the regional level. We then coupled these travellers with the airports served and distributed these in the most logical way where more airports connect the same region or country. The travel databases provide flows per transport mode, so we could filter out the air travellers and compare the totals per airport-airport relationship with those in the air passenger database. If there are more passengers than travellers, we assume the difference represents transfer passengers. This procedure has given us an estimate of the share of transfers at the airport level (and thus also at the city and country levels).

We have compared the data in our database with the aggregated data published by, for instance, Schiphol Airport. The last step was adding data about travel spending and other economic indices like trade volumes. An important note on travellers: we define origin-destination passengers/travellers as those who travel from their home address to a destination address and back. Almost every O/D passenger/traveller not travelling by car uses multiple modes because there is always some transport from the front door to the airport, railway station or bus stop or to get to the destination's front door. This definition contrasts definitions used in air transport studies that define O/D-travellers as direct flying passengers between two airports, disregarding their real origin address and destination address.

6.2 Database construction

For the modelling exercises, we have created a database that combines the following data sources:

1. Eurostat data for both passengers and flights from the 5 main Dutch airports per destination airport (Eurostat, 2023).
2. The inbound data from NBTC for 2014 (data from NBTC (see description by Neelis, Pels, et al., 2020); corrected for growth to 2019 based on CBS data; data contain spending per visitor).
3. Business travel by Dutch people (see description by Neelis, Peeters, & Eijgelaar, 2020); includes data on spending.
4. Outbound leisure travel by Dutch tourists (NBTC-NIPO, 2020); includes data on spending.
5. Some CO_2 emission data for aviation (Peeters & Reinecke, 2021)

Based on the above, we created a database for the main Dutch airports (Amsterdam Schiphol Airport, Eindhoven Airport, Rotterdam/The Hague Airport, Maastricht/Aachen Airport and Groningen Airport) for 2019. The database contains all known destination airports and has also been grouped for all cities involved (in some cases, several airports serve one city) and further aggregated to the country level. Furthermore, a list of all countries and regions visited by Dutch leisure and business travellers, plus all source markets for visitors to the Netherlands, have been combined and attached to cities and airports. These data have been added to the flights database, adding additional lines where a country, city or airport has no direct flights with a Dutch main airport.

The database contains 264 airports for 253 cities in 145 countries. The table shows 60.62 million on AMS and 5.96 million passengers from other airports air passengers (counted at arrival and departure). In total, we gathered information about 45.7 million O/D travellers for all modes, of which 48% by air, 9% by train/bus/ferry, 42% by car and 1% by other modes. Inbound forms 36% of trips and Business 22%. We calculated several additional parameters for the year 2019, the most important of which are:

- Transfer passengers AMS: by subtracting the sum of all O/D-travellers indicating they used air transport to travel to or from the Netherlands based on the NBTC databases (times two as they count when arriving and when departing) from the number of pax for Schiphol an estimate of transfer passengers per direct connection between Dutch and foreign airports is made. Overall, this shows 49% of transfer passengers. Schiphol publishes monthly aggregated data[10], which we used to compare with our aggregated results. We determined that the monthly transfer share varies between 35% and 40%. The cause for this discrepancy might be that for some connecting airports, our database of O/D-travellers contains more arrivals at a Dutch airport than the passenger data show. In such cases, we cut off the

[10] See https://www.schiphol.nl/nl/schiphol-group/pagina/verkeer-en-vervoer-cijfers/. Unfortunately, these data are given at a high aggregation level, while we need the shares for each airport directly connecting to Schiphol.

total travellers to 100%, which means we lose some travellers, thus increasing the share of remaining transfer passengers. This data deficiency might be caused by, for instance, Asians flying to Germany or Belgium and arriving in another mode in The Netherlands. At the same time, we assume them all to only fly into the Netherlands. Unfortunately, it is impossible to use the Schiphol data about transfers because these do not give the shares per destination, which we do need to find the economic value of each connection to a destination (city, airport, country).

Direct revenues in the Dutch economy from travellers (see assumptions in

- Table 5) accumulate to 19.2 billion, of which 49% comes from flights. Total revenues are generated 61% by inbound, 35% by outbound and 4% by transfer passengers.
- The total international connections for air (take-offs and landings) are 406,000 from AMS, some 50,000 from the other four airports and 340,000 by international train for destinations with less than 17 hours travel time.

6.3 Some characteristics of the dataset

We developed three databases: one for each airport, one for cities close to the airport and one for countries where the airports belong to. Table 1 shows the number of destinations.

*Table 1: number of destination airports in our database (including destinations **not served** with direct flights).*

Category	Nr of airports in the database	Served by AMS	Served by the other four airports	O/D travellers[11] without a direct connection
Total number of destination airports	264	56.1%	14.8%	29.2%
Total number of destination cities	253	56.5%	15.4%	28.1%
Total number of destination countries	145	46.9%	12.4%	40.7%

Of the total of 45.7 million travellers in the airport database, 30% travelled on flights without transfer passengers, 2% on flights with only (>99%) transfer passengers, 36% to places without a direct connection (very close and far away mainly) and 67% with a mix of O/D and transfer passengers (see Table 2).

Table 2: Travellers (all modes) per type of flight connection (all Dutch airports). Note: the sum of values is higher than the total due to overlapping categories.

Kind of connection	Total travellers (*1000)	Share of O/D pax
Flights (all airports) with zero transfers	13,485	30%
Flights with mainly transfer passengers (99%)	698	2%
Airports where OD travellers go without a direct connection from Dutch airports	16,619	36%
Flights with a mix of transfer and O/D	28,369	62%
Total travellers	45,686	100%

Table 3 shows a range of different categories of travellers. Leisure and outbound still dominate the O/D travellers by air. For other transport modes, this is even stronger, with leisure other transport covering 55% of all travellers.

[11] The term O/D-traveller is used as in the tourism transport literature and means any traveller between an address in another country and an address in the `Netherlands, disregarding the number of transfers.

The train is used more by outbound than by inbound travellers. Business travel depends mainly on aviation (64%). For leisure, this is 44%. Transfers at AMS cover 49% of all passengers.

Table 3: Number of travellers in the database for O/D and transfer categories and transport modes. Note: each traveller counts two times to align with the number of passengers counted as arrival and departure.

Type of traveller	Total travellers (*1000)	Share of O/D*)
Business flights	6,433	14.1%
Leisure flights	15,645	34.3%
Inbound flights	8,156	17.9%
Outbound flights	13,922	30.5%
Business train	561	1.2%
Leisure train	1,702	3.7%
Inbound train	913	2.0%
Outbound train	1,350	3.0%
Business car/other transport	3,093	6.8%
Leisure car/other transport	18,223	39.9%
Inbound car/other transport	7,369	16.1%
Outbound car/other transport	13,947	30.5%
Travellers AMS (includes transfers)	30,309	66.4%
Pax Other airports	2,978	6.5%
Transfers AMS (share of AMS)	14,839	49.0%
Total pax AMS 2019	45,657	100.0%

*) *This share draws upon total travellers that fly through Amsterdam or, if they travel within another mode, would have gone through AMS when they had chosen air transport.*

Table 4 provides an overview of passengers at all Dutch airports and the number of aircraft flights for AMS only. Only 27% of all passengers at Dutch airports have no possible rail connection. Our travel databases consider train trips longer than 18 hours (basically the maximum for a daytime trip) or connections with no rail travellers impractical for rail travel. So, we only include 'possible' rail connection and assume 'no rail connection' when the connection fails the above two criteria. Our databases show that many people take much longer train trips. Also, air travel ranges from just a couple of hours to more than 24 hours for the longest trips. Therefore, we assume that up to 17 hours of daytime train connection or zero rail travellers in the inbound and outbound travel data is possible, even though such long trips do not capture large shares of travellers. We also added train trips of less than 9, 6 or 4 hours to show this market share effect. Regarding flights, the share is 7%, which is higher because the aircraft used on longer distances have higher seating capacity. Some 20% of all flights from AMS have less than 10% O/D passengers on board, which covers about 11% of all travellers.

Table 4: Overview of some characteristics of the city-based data.

Kind of connection	Travellers at all airports (*1000)	Share (%)	Flights from AMS (a/c)	Share (*%)
Flights (all airports) without transfers	6,799	15%	57,308	14%
Flights with <10% O/D passengers	4,976	11%	82,556	20%
Airports with traffic not served	2,047	4%	n/a	n/a
Flights to cities with GaWC<10	5,476	12%	50,417	12%
Flights with <=4-hour train connections	1,490	3%	26,776	7%
Flights with <=6-hour train connections	4,579	10%	75,987	19%
Flights with <=9-hour train connections	9,139	20%	154,150	38%
Flights with <=1-hour train connections	16,634	36%	256,222	63%
Total	45,657	100%	405,684	100%

We also looked at the shares of aircraft movements at AMS as a function of rail alternatives with different rail travel times.

Table 4 also shows that 3% of all travellers have a good rail alternative (< 4 hours), which covers 7% of all flights from AMS. For rail connections less than 6 hours, this quickly rises to 10%. As travel speeds by car tend to be somewhat higher, we may assume that the most suitable rail connection also provides a possible alternative by car. Though even 4 hours might look like a long travel time by train compared to less than one hour of flight time, one should consider the following:

- Access and regress time usually take a relatively large share of total time on short-haul flights. Four hours may seem a lot, but on a flight of 1 hour, the actual time difference between using a train and flying can be less, given that many stations are located in city centres.
- Labour shortages affect aviation and rail alternatives. If you can fly from Schiphol, waiting times can be long, especially during holidays. So the time difference, including access, regress and waiting time, maybe rather low.

Though the literature considers a train travel time of less than 2.5 hours as fully competitive with air travel (EEA, 2020), our database shows rail travel of up to 17 hours journey by train (mainly business). Those longer train trips avoid longer flights and, in terms of the environmental impact prevented, weigh several times heavier as flights replaced by a <4-hour train ride.

6.4 The I&W network quality indicator

In the box "The I&W NQI" in Chapter 1, we describe the I&W network quality indicator (NQI), which is composed of a combination of the GaWC index of all destinations and the square root of the current capacity to those destinations. The final network quality is the sum of all individual ND contributions times the overall NB factor. In this way, the individual contributions to ND can be used as a proxy for the contribution to the overall network quality. We will index the I&W proposed network quality indicator as follows: NQI_{GaWC}.

Figure 1 shows the relationship between the number of flights per GaWC city and the GaWC index. Cities with a GaWC of less than 10 points are excluded, as proposed by the I&W method. The graph and the trendline show there is a weak but significant (N=105, Pearson's correlation is 0.231, Significance 2-tailed is 0.018) relationship between number of flights from AMS and GaWC. This finding means that current flights serve high GaWC-index cities slightly better than low GaWC-index cities, regardless of the distance to them.

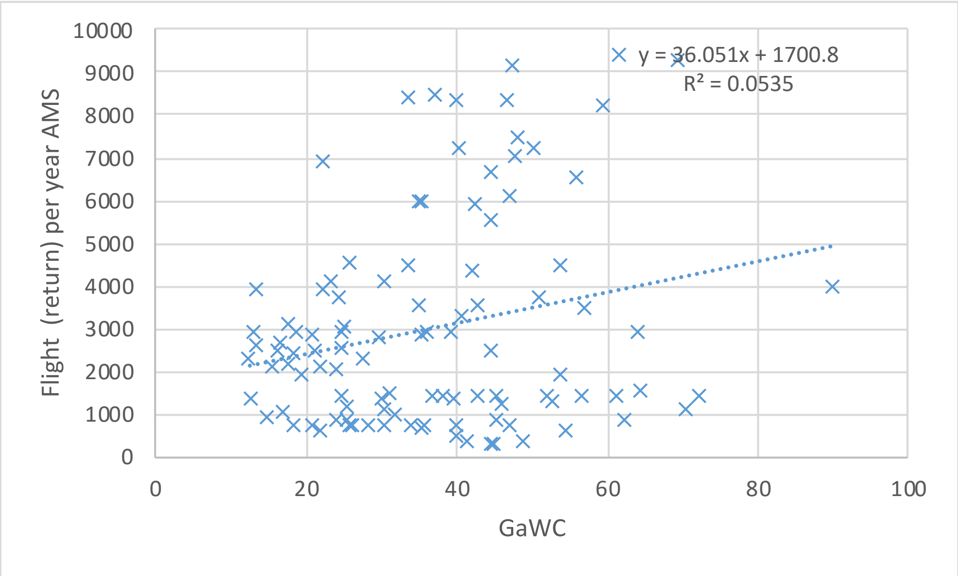


Figure 1: the relationship between the number of flights from AMS and the GaWC index for the Netherlands. Note: London is an outlier with double the GaWC and triple the next city's number of flights, so we have left London out of this graph.

In Figure 2, we plotted the I&W-inspired GaWC times the square root of seats. This metric represents the Network Depth part of the NQI_{GaWC} per city. Now, there is a highly significant relationship with flights (N=105, Pearson Correlation is 0.649** and Sig. (2-tailed) is <0.001) as shown in Figure 2. However, this is expected because the number of seats has a direct relationship with the number of flights itself: the parameter on the y-axis is not independent because it has partly been calculated using a parameter directly related to the values on the x-axis. Conclusion: the current distribution of flights over airport pairs is only weakly related to the importance of ten cities served by the destination airports (the GaWC index).

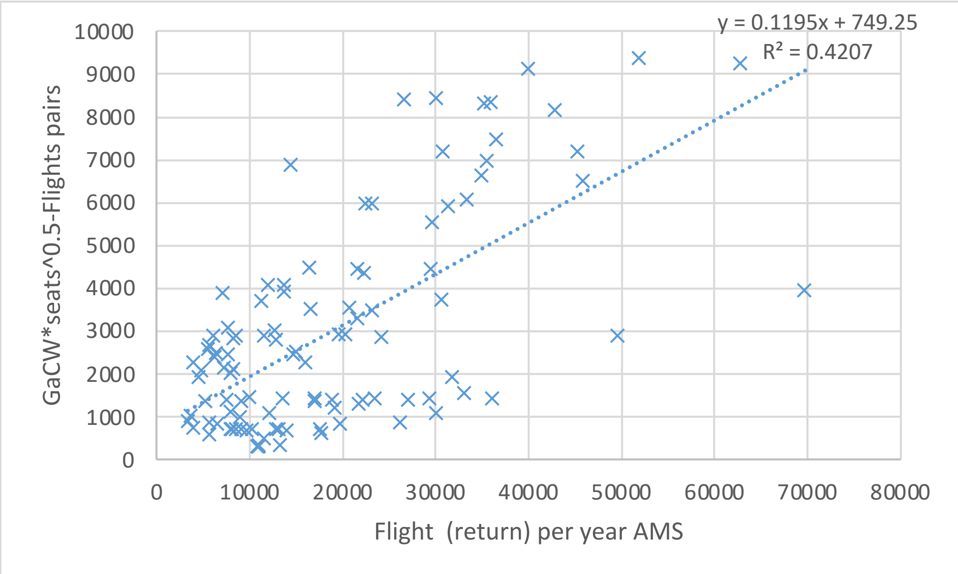


*Figure 2: the relationship between the number of flights from AMS and the GaWC*sqrt(seats), the ND part of the index for the Netherlands NQI_{GaWC}. Note: London is an outlier with double the GaWC and triple the next city's number of flights, so we have left London out of this graph.*

Suppose you want to use the NQIGaWC as a way to determine how to cope with changes in capacity at AMS efficiently. In that case, it can be helpful to determine the impact on incremental changes of NQI_{GaWC} as a function of changes in flights from AMS. For this, Lorenz curves are often applied (Kleiber, 2005). The Lorenz Curve was initially developed to study income distribution and poverty indicators. Its income definition is: "The Lorenz Curve exhibits income distribution by plotting the interdependence of two functions derived from the income density function, i.e., the percentage of total income earned by the percentage of population" (Levine & Singer, 1970, p. 324). The essence of a Lorenz curve is that you plot for both the x and y-parameters the cumulative shares of between 0 and 1. They were originally developed to show the inequality of income distribution over a population. So what you do is you order the population from lowest to highest income, calculate the accumulated share of each of the people and plot that against the accumulated share of their income. In an unequal distribution of income, the line sags below the equality line and gives an indication of how unequal the income is distributed[12].
In our case, the 'population' is the number of flights and the 'income' is the GaWC or any other network quality indicator accumulated per flight. To clearly show the unequal contribution of certain destinations to ten total, we have ordered the flights in the database for lowest to highest indicator (e.g. GaWC). If the curve is a straight line between the points (0%, 0%) and (100%, 100%), all flights add equally to the network quality, and 'preferential destinations' do not exist. As one of the goals of the Ministry is to identify preferential destinations, an index that is always a more or less straight line is not useful for this purpose.
Figure 3 shows the Lorenz curve for the data ordered descending for flights from Amsterdam (the graph starts at 5% of flights, the share of flights to London). The orange line shows the indifferent line (every 1% of the change of number of flights causes 1% in NQI_{GaWC}). The graph shows that even sorting flights from lowest to highest

[12] See further explanation in https://www.investopedia.com/terms/l/lorenz-curve.asp.

contribution to network quality shows hardly any opportunities for reduction of flights. The relatively biggest impact could be achieved by removing the first 20%, which would reduce NQI_{GaWC} by only some 15%.

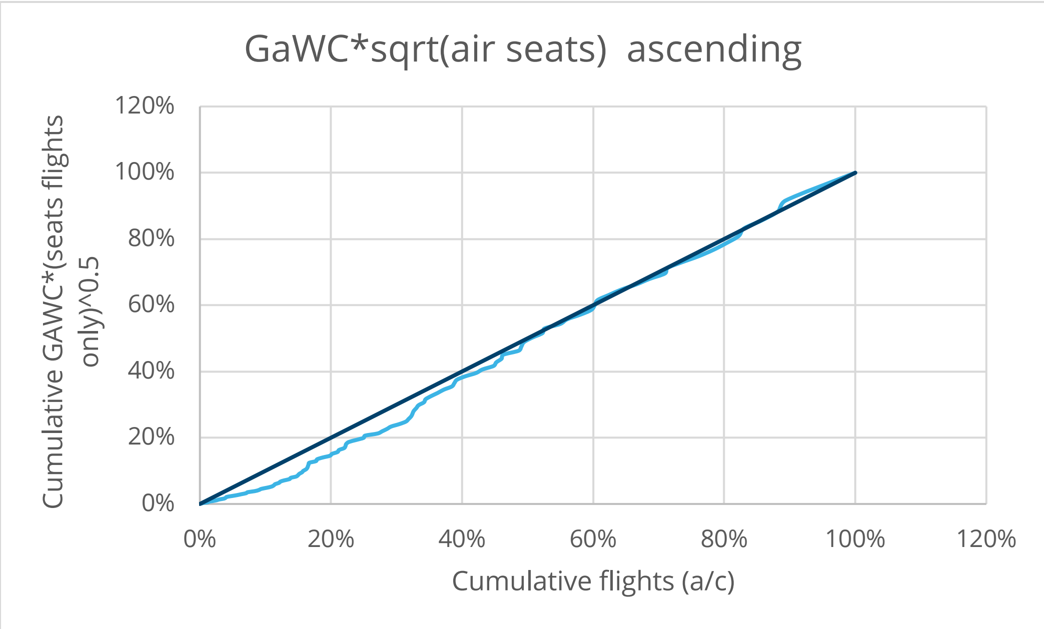


Figure 3: A Lorenz graph of the increment of NQI_{GaWC} of flights from AMS

However, one could also 'shave off' most flights from connections with most flights to preserve connectivity (the destination) while reducing high frequencies. We tested this method and found that the optimum reduction (most flights per connection removed at least economic damage) that can be reached is 21% of flights at 12% of NQI_{GaWC}. In that case, London would receive only 1600 flights per year compared to its current 38,000. When constrained to 10,000 flights per year, the resulting reduction in flights is 16% at the cost of 8% of network quality. Already in 2009, (Givoni & Rietveld, 2009, p. 503) noted about the London-Amsterdam market that "Lowering frequency will probably not disbenefit passengers significantly in this market". Currently, several direct high-speed train connections further erode the importance of the flight-connection. However, the indicator proposed by I&W ignores the other transport modes and does not directly represent the economic impact of all kinds of international travellers, including those travelling for leisure and outbound and inbound. In the next section, we propose a 'revenue-driven '-indicator.

6.5 Adding the train to the frequencies

Using the international timetable from DB (https://reiseauskunft.bahn.de) we determined the travel time and frequency for all connections less than 1250 km between Utrecht and the main station of the arrival city. When the travel time was more than could be covered during the day-time (>17 hours), we dismissed the connection. The frequency was counted by counting different arrival times (differing by at least half an hour). These requirements are used to select 'possible' rail connections, not what current travellers or

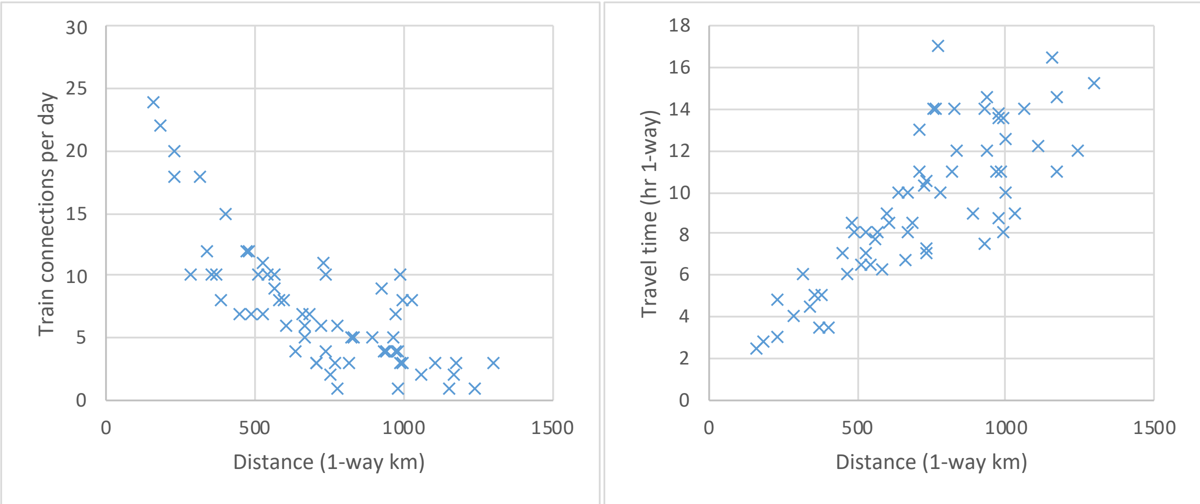


Figure 4: Quality of train connections in terms of connections per day (left) and travel time from Utrecht Centraal to the city's main railway station (right) as a function of the 1-way travel distance (great circle distance).

With these frequencies added to the NQI, we created NQI_{GaWC_R} based on the combined air and rail seat capacity. Of course, only GaWC cities are included in the index. The rail capacity was assumed to be related to all non-flying O/D passengers, which currently is not always the case. These analyses revealed an important shortcoming of the NQI_{GaWC}: the international connectivity of the Netherlands would increase from 406,000 connections (air) to 586,000 connections (air plus rail). Furthermore, as part of the rail connections to, for instance, London and Paris connect to GaWC cities, this would add 47% to the total NQI_{GaWC}. For the Lorenz graph and the shares of flights, NQI_{GaWC_R} does not change much, as Figure 5 shows. Therefore, we explore other indicators that directly link flights to the Dutch economy in the following sections.

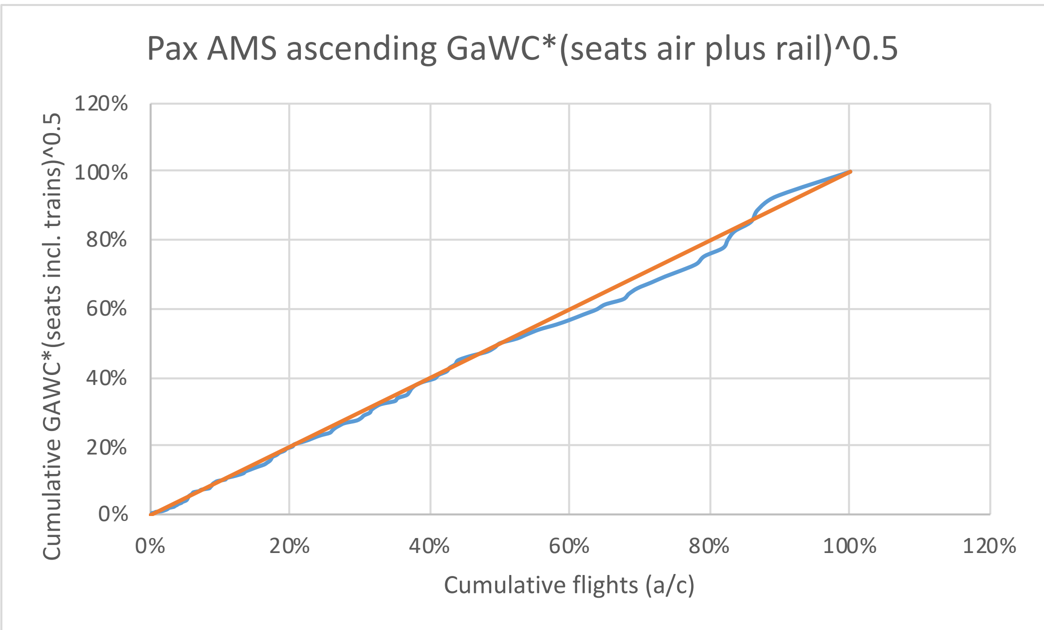


Figure 5: A Lorenz-graph of the increment of NQI_{GaWC_R} of flights from AMS.

6.6 A revenue-driven indicator

Though the GaWC-based indicator proposed by I&W is meant to help safeguard the economic value of the network, Ministerie van Infrastructuur en Waterstaat (2022b) does not further show their indicator to be able to do so. In this section, we explore just this relationship and extend it to how to enable de-growth at the least

economic cost. Rather than trying to assess the network quality itself, we now will look at the direct economic contribution of the direct connections to cities worldwide. For this, we use direct spending by the travellers within the Dutch economy as the indicator. This metric does not cover the full benefits, but it is an indicator for which we have data at the low aggregation city level. Also, indirect effects are often added as multipliers of the direct impacts, which means that the total numbers change. Still, as discussed earlier, indirect effects are often uncertain, and if they exist, they are the effect of market failure.
We developed the ' revenue indicator ' to determine the direct revenues of the main types of travellers. This indicator is based on the actual spending of O/D-travellers and transfers passengers into the Dutch economy. We calculated it based on the direct spending of international overnight visitors and the share of spending in The Netherlands by outbound visitors. The direct spending within the Netherlands by transfer passengers is difficult to assess. Still, we estimate it based on the transfer pax airport charge and an assumption about spending in shops and restaurants.

Table 5 gives the assumptions. Furthermore, we added the climate external costs of flights, the majority of externalities of travel (Peeters et al., 2007) using the current cost of carbon in the EU Emission Trading System, an average emission factor for all Dutch air travel and assume the climate impact to be three times larger as the CO_2 effect (see references in

Table 5).

Table 5: overview of the assumptions for the direct revenues of different types of travellers to and from the Netherlands.

Pax type	Revenues per pax	Source
WF_Inbound	€ 679.50	The number is the average, but we used measured data for 40 countries and five world regions covering the other countries. All are based on (Neelis, Pels, et al., 2020) but only account for revenues spent during the trip in The Netherlands.
WF_Outbound	€ 223.82	Vermeulen et al. (2020)
WF_Transfer	€ 50.00	Transfer pax charge is €7.39 (Annual report Schiphol 2022); spending on shops and restaurants is unknow.
Climate cost per ton	€ 100.00	The current price is €104 (01-03-2023) but has increased 52% in the past year; https://tradingeconomics.com/commodity/carbon
GHG Emissions (kg/pkm)	0.288	CO_2 based on (Peeters & Reinecke, 2021) multiplied by an equivalence factor of 3.0 (Lee et al., 2020) to arrive at full climate cost, including non-CO_2 effects.

From this exercise, we learn that 43% of all direct revenues come from visitors flying to, from or through the Netherlands. Non-flight international travellers generate the remainder (see Table 6). Note that we excluded domestic travel, which is good for about half of the tourist trips in The Netherlands. Adding the external costs of aviation leads to a substantial reduction of direct revenues, up to 23% for the aviation part and 13% for the total. These externalities ignore the cost of climate change caused by other transport modes, which would accumulate to some 10-15% additional external costs.

Table 6: Main results of the direct revenues from international travel to and from the Netherlands.

Scope of economy	Revenues (billion)	Revenues reduction due to climate cost (CO_2 only)

Economy for flights only	€ 10.72	n/a
Economy for all trips	€ 18.81	n/a
Economy for flights only (climate-corrected)	€ 8.28	23%
Economy for all trips (climate-corrected)	€ 16.37	13%

The relationship between GaWC and the direct revenues of international travel is relatively weak and might be even negative in the higher regions of GaCW (Figure 6). The graph gives the result for inbound tourist revenues (spending during the trip in the Netherlands) as a function of the source market (the country people the visitors live in) plus spending per outbound and transfer passenger, as shown in

Table 5. The relationship is significant. A linear relationship shows a continuous increasing line and is also significant. We checked the best-fit curve with FindGraph (Vasilyev, 2013), which appeared to be the 3rd-order polynomial, as shown in Figure 6. The trend line shows that at the higher values, the economic revenues tend to decrease again. Note: London has been removed because it is an extreme point both in terms of revenues and number of flights.

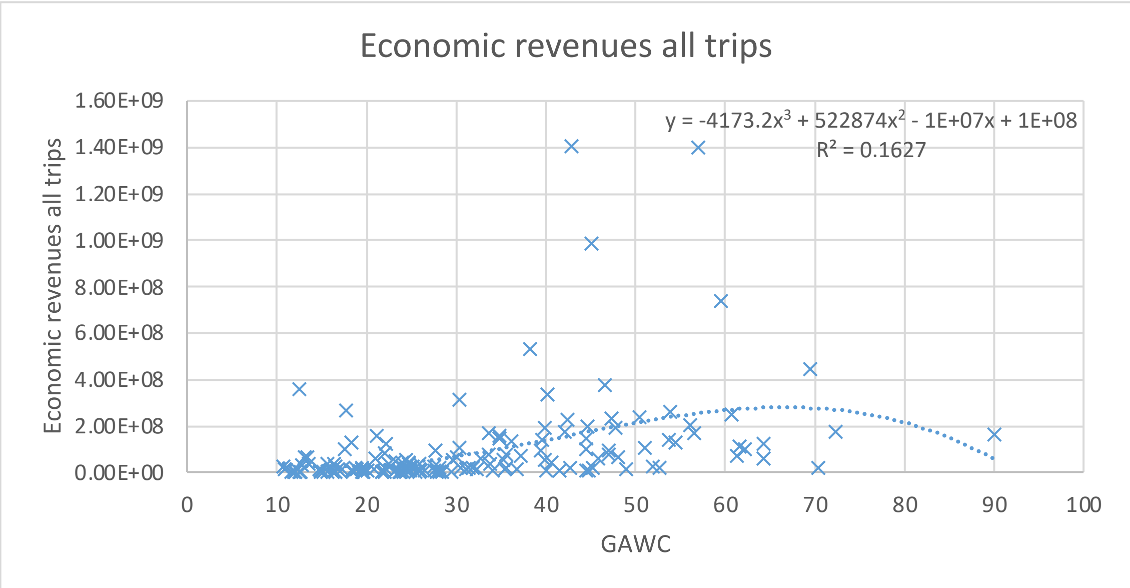


Figure 6: The relationship between GaWC and the total revenues of international travel.

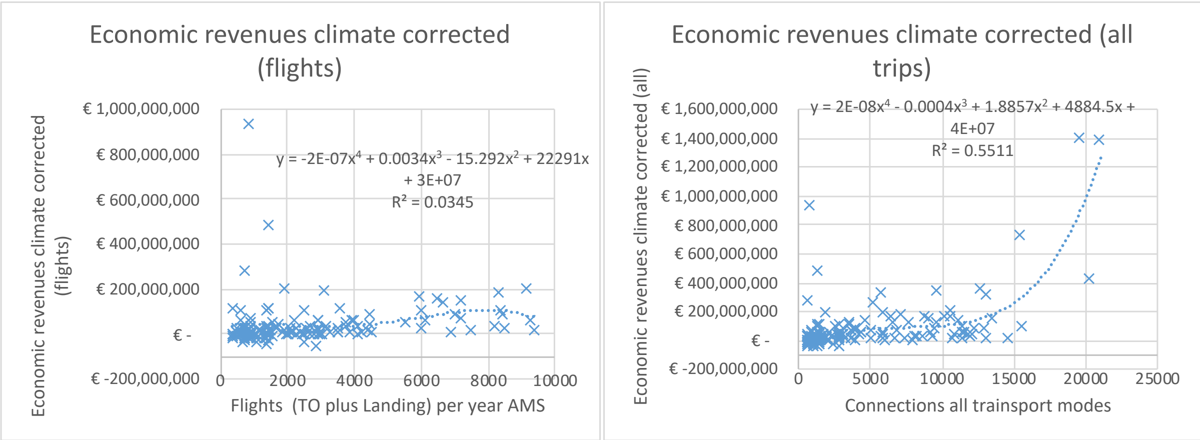


Figure 7: The number of flights and the direct economic contribution of travel to the Dutch economy for economy contributions of flights (left) and contribution of all international travellers (right).

Figure 7 shows the difference between the economic revenues, when corrected for climate cost, for flights only (left graph) and all transport modes (right). This graph reveals the importance of looking at the whole international connectivity and not only that by air. First of all, the total revenues covered by non-air transport are significant and secondly, the relationship between the connections and revenues becomes clearly positive rather than indifferent.

To explore whether the all-inclusive method (based on all air and rail connections and revenues for all trips minus external costs) provides more opportunities for optimising flight reductions, we drafted Figure 8. This graph clearly shows the scope for the reduced number of flights without any net economic impact (up to about 30% of flights removed would not change the revenues). Even removing 40% of the flights causes a loss of just 6% of revenues. But, as many of those flights cover short distances, other transport modes would likely take over the connectivity and thus reduce the economic loss.

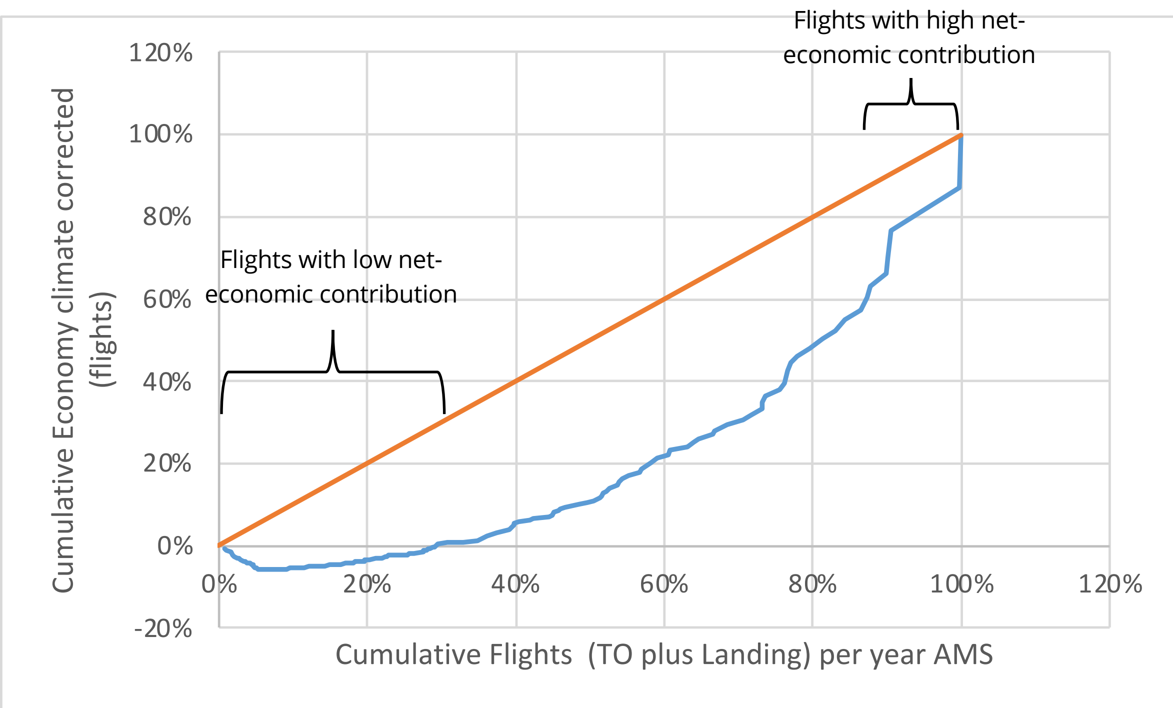


Figure 8: Lorenz graph showing the relation between flights from AMS and net-economic revenues (revenues minus climate cost) for all air travellers, including correction for aviation's climate impact.

The first 30% of flights populating the accumulated flights to the left of the graph are distributed over 70 (49%) of the 143 cities in the database with direct flights from AMS. Removing these would not affect the net economy of The Netherlands. The graph provides some examples of cities[13].

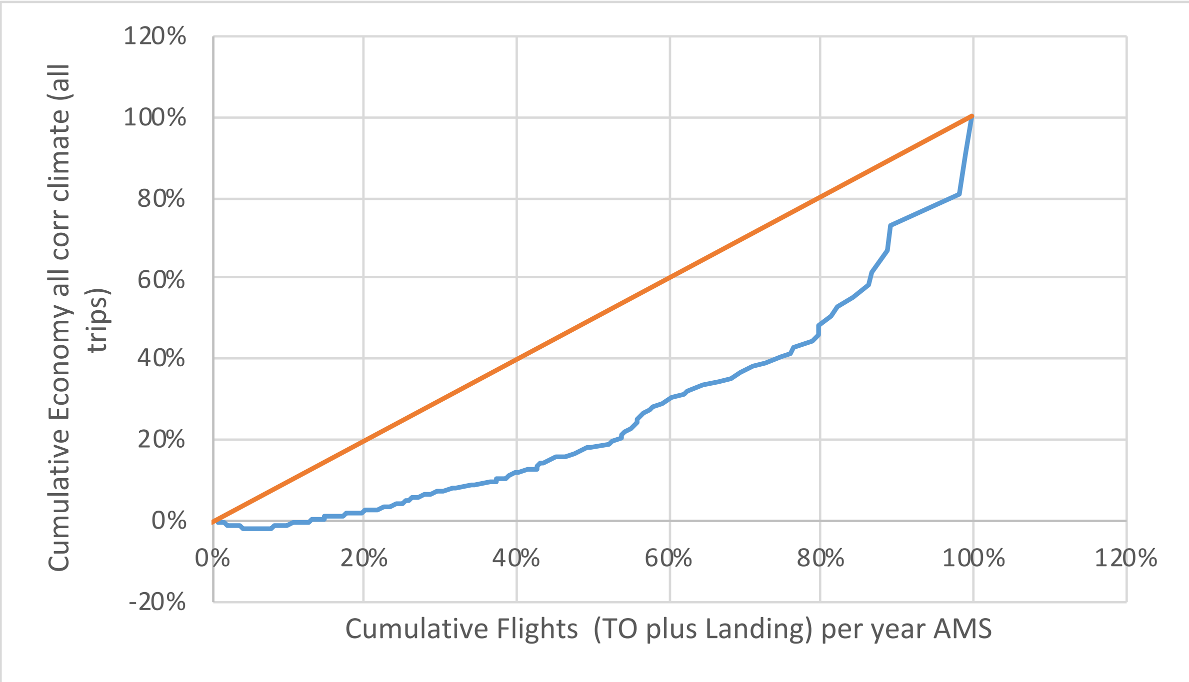


Figure 9: Lorenz graph showing the relation between flights from AMS and economic revenues for all air travellers, including correction for aviation's climate impact.

We can also plot the total economic revenues for all transport modes against the flights to AMS (Figure 9). Interestingly, the 18% of flights at the other end of the graph, with a high net impact on much of the economy (those between 82% and 100%), are the following: Düsseldorf, Brussels, London, Frankfurt am Main, Paris, Munich, Bremen, and Berlin, which have better connections by train except Bremen, Berlin, and Munich. Collectively, these latter destinations represent 15.3% of all flights. So, the direct economic revenues of the passengers to AMS can be maintained while removing 15% of the connections at long-haul and gradually replacing another 15% at the short-haul end. In this way, it is possible to define preferential connections based on ten net economic impacts.

6.7 Trade balance as a metric

Another way to examine the importance of connectivity and the economy is by looking at macroeconomic parameters like trade flows and balance. To explore this method, we first try to find relationships between connectivity and trade volumes. High trade volumes and trade balances are indicators of economic activities and, thus, of the economy as a whole. We roughly investigate whether there is a relationship between trade and the number of all travellers, trade, and flights. To do so, we used detailed per-country data for 2017 from CBS (2018). Unfortunately, CBS does not provide newer versions of per-country data, so we used those for 2017. Figure 10 shows the relationship between trade volume and return trips from AMS and the O/D travel by all modes. Also, the relationship between positive trade balance and number of flights is rather indifferent, while this relationship seems more positive in the case of all transport modes for O/D-travellers only.

[13] The list of cities needs to be considered with care: the exact list much depends on the share of transfers and the exact flight-routes that OD-passengers take which both are not publicly known, but can of course relatively easily be provided by the airlines or though survey by the airports. So, the list of cities is based in assumptions over flight-routes, but these can be in some cases deviate from reality. This, however, does certainly not mean that there are not such cities, only that these cannot be identified based on public data.

Figure 10: Relationship between trade balance and number of flights (blue crosses) or overall trips (orange circles). Trendlines represent 3rd-order polynomials.

In Figure 11, we show the relationship between the flights from AMS and the number of O/D travellers for all modes as a function of total trade volume, i.e. the sum of import and export value for each country. Of course, now all trade volumes become positive. The relationship with flights from AMS is varied, but not just positive, while it is positive for all O/D travellers.

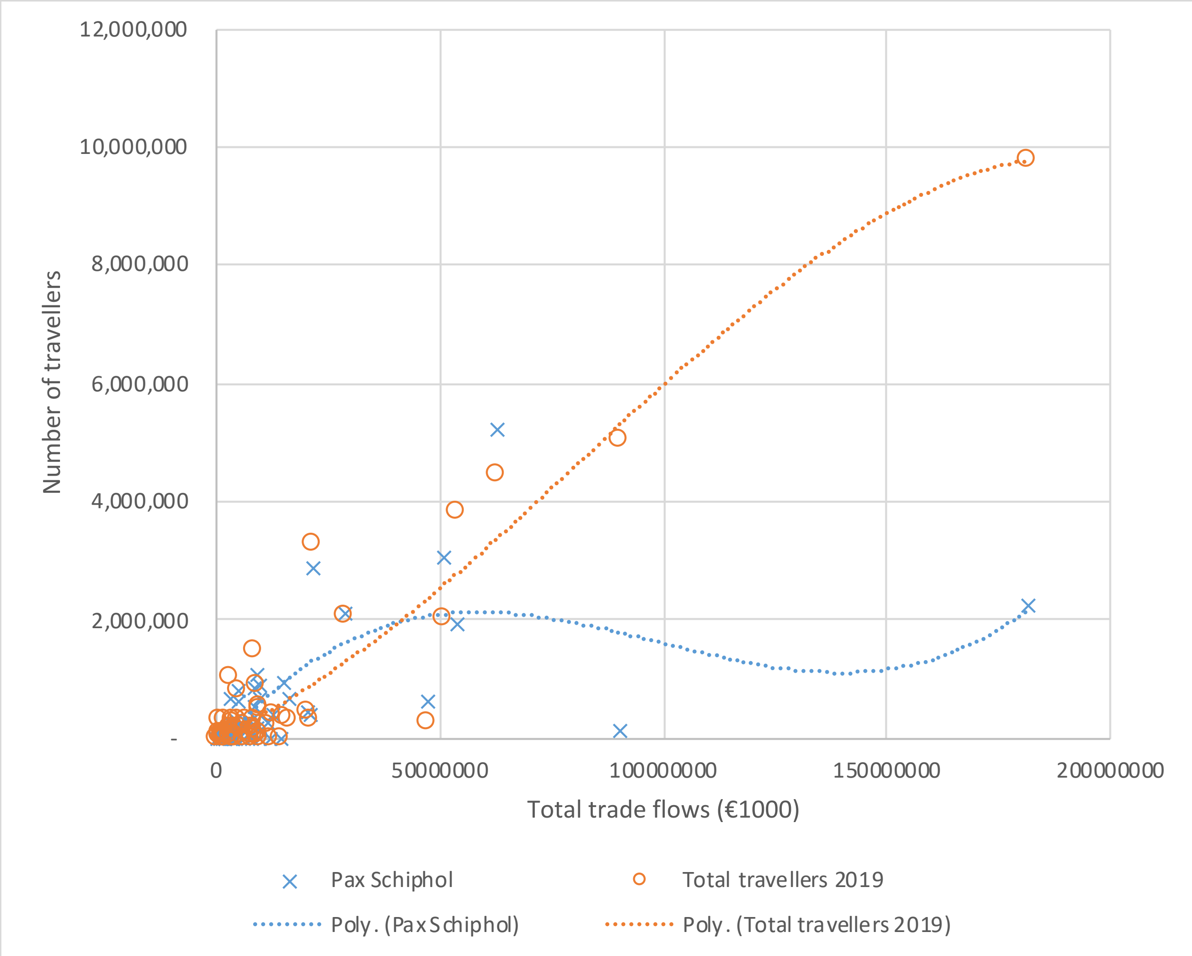


Figure 11: Relationship between trade volume (sum of import and export) and number of flights (blue crosses) or overall trips (orange circles). Trendlines represent 3rd-order polynomials.

Figure 12 shows the Lorenz curve for the total cumulative trade volume. This figure shows some areas of low contributions to the trade volume per flight added (for instance, between 17-23% and 40-57% of flights.

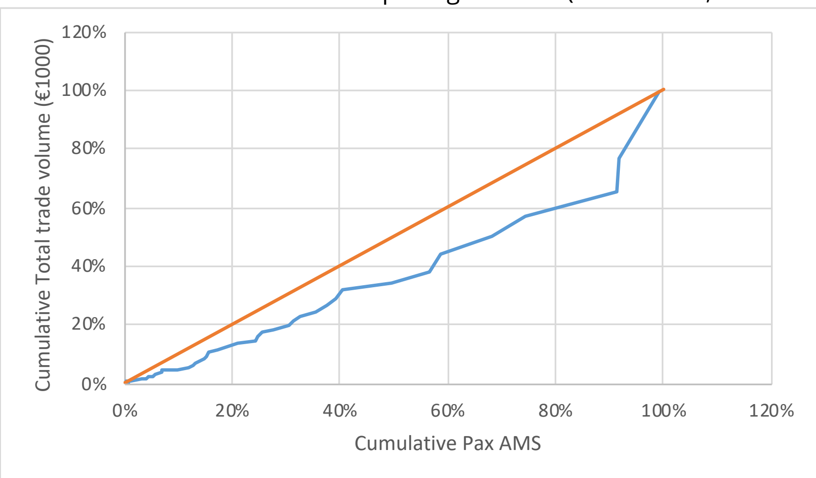


Figure 12: cumulative total trade volume as a function of cumulative passengers from AMS (ordered trade volume from low to high).

6.8 Other metrics for connecting airports

As a direct alternative to the NWQ_{GaWC} indicator proposed by the I&W, we found some other network quality indicators from the literature study discussed in sections 2.3.1, 2.3.2 and 5. This section will explore how these alternative NQIs relate to the economic goals. We explored two more metrics: the Global Aviation Connectivity Index (GACI; Cheung et al., 2020) and the 'betweenness centrality' (Song & Yeo, 2017). This index could be an alternative to the GaWC-based index proposed by the Ministry.

The relationship between flights and O/D flights and GACI seems not very strong, as Figure 13 shows. However, Figure 14 reveals a more positive relationship between the Betweennes and the Degree centrality as defined by Song and Yeo (2017). Degree centrality is based on the number of direct connections between airports. The Betweenness centrality indicates the shortest connections (shortest in terms of time, cost, or distance) that run through a certain airport. So the difference is that Degree centrality considers only direct flights, while betweenness also includes connecting flights. Again, the relationship seems strong because the number of connections is not independent from the frequency of flights on each connection. This metric thus suffers from the same build-in relationship as with the NQI proposed by the Ministry.

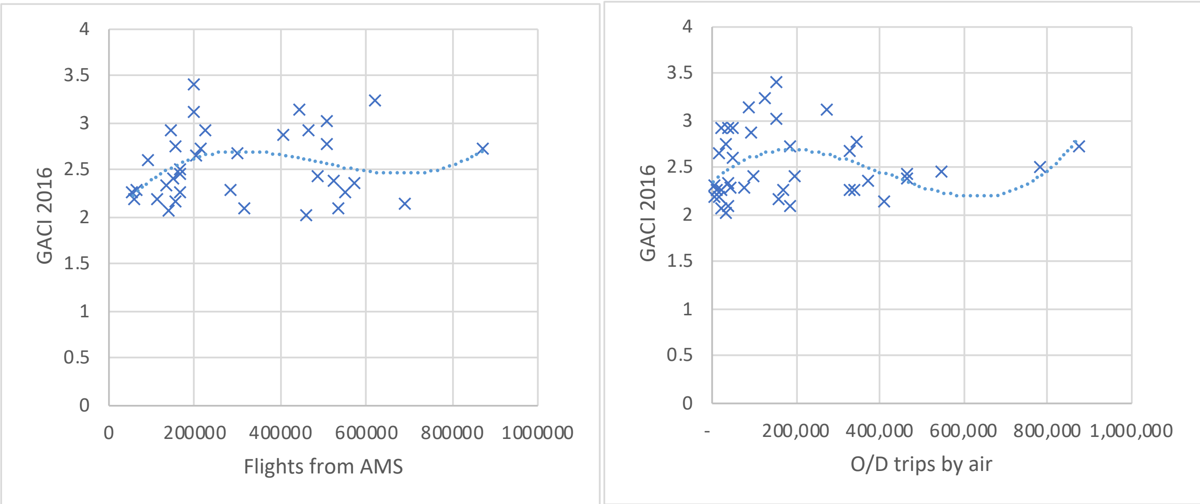


Figure 13: the relationship of GACI as a function of the number of flights at AMS, including transfer passengers (left) and only O/D travellers (right), based on data given by Cheung et al. (2020). Note: only those airports with a direct connection to AMS have been incorporated.

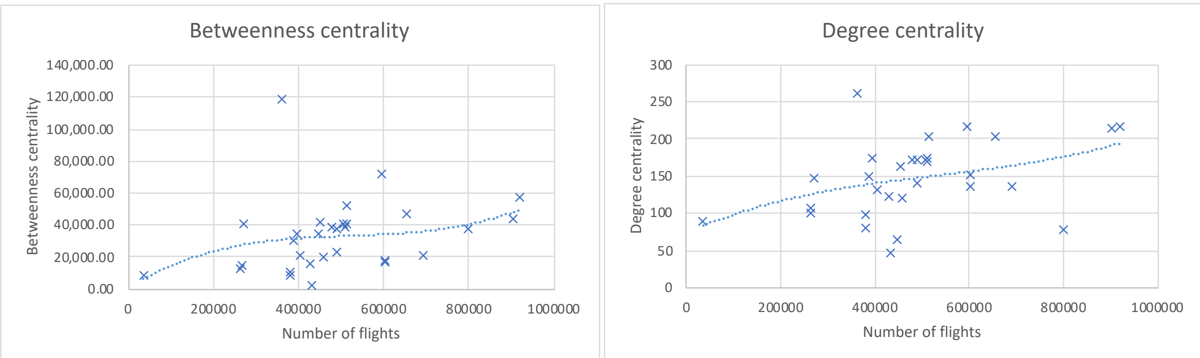
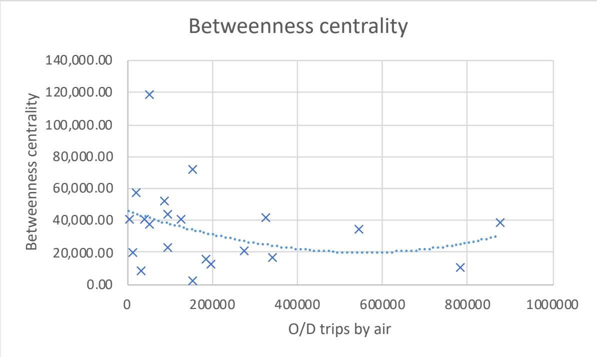


Figure 14: the relationship between Betweenness centrality (left) and degree centrality (right) as a function of the number of flights at AMS, including transfer passengers, based on data given by Song and Yeo (2017). Note: only those airports with a direct connection to AMS have been incorporated.

We also assessed the relationship between both centrality indicators and OD flights only, as shown in Figure 15. Now, the relationship becomes weak again, indicating the role of transfer passengers in airport centrality.



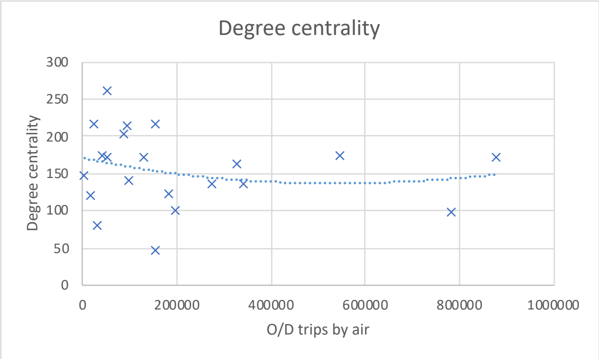


Figure 15: the relationship between Betweenness centrality (left) and degree centrality (right) as a function of the number of flights by O/D travellers at AMS (excluding transfer passengers) based on data given by Song and Yeo (2017). Note: only those airports with a direct connection to AMS have been incorporated.

Note that we could only use the limited number of published points of GACI and centrality. Therefore, in the above analysis, we could include only a small share (some 20%) of all connecting airports to AMS. These were the airports with the highest indexes. We requested the existing larger datasets from the authors of the two papers, but they did not respond. The overall conclusion here is that there might be some potential in GACI and centrality, but they also suffer from the same issues of circle reasoning as the NQI proposed by the Ministry suffers from ("more connections make an airport more important because it has more connections").

7 Conclusion & Recommendations

7.1 Conclusions

The importance of the network quality framework lies in its impact on the Dutch economy. The proposed indicator by the Ministry only looks at the GaWC ranking of current destination cities with a direct flight and the capacity currently offered by all airlines on these connections. This approach aligns with findings from the scientific literature, which show that the metrics used to measure network quality are based on operational supply. Though it is useful to compare the relative connectivity and transport quality of different destination airports, such metrics do not very well capture the full understanding of network quality. Furthermore, this network quality indicator ignores airline behaviour shaping the network and, for instance, the shares of transfer passengers versus passengers visiting the Netherlands.

Moreover, it fails to include the significant environmental and social costs of certain connections compared to their direct economic revenues. It thus ignores some vital insights from the air transport literature about the broader political goals for the wish to have a high-quality air network. The Ministry-proposed indicator says that removing 1% of the flights from the network generally costs 1% of the network quality indicator's level. In that way, it cannot inform policymakers or the sector how efficiently degrow the main hub, at the least possible damage.

Also, the preferential destination part of the proposed quality index, the GaWC index, does not represent the important cities for all elements of the Dutch economy. The cause is that the GaWC index only looks at international companies' networks and not at popular holiday destinations or inbound tourism source markets. The above is exactly the point of this debate: does it make sense to define a list of important cities to form a kind of optimal network, independent of the current origin-destination relationships between the Netherlands and other countries and to exclude significant amounts of connectivity through different transport modes road, rail, water)?

In this report, we show the I&W proposed indicator is not well-related to the overall goals of the aviation policy of the Dutch government, which are improving the business climate, the airport's competitive position and the well-being of the Dutch population. The network quality indicators are best suited to inform the second policy goal but tell nothing about the first and third and ignore the wider economic relevance of aviation like revenues from the travellers, macro-economic parameters like trade volumes, externalities like climate costs and the potential role of other transport modes on certain routes in the network. Focusing only on aviation competitiveness may serve the aviation industry, but, as we have shown, it fails to serve the wider Dutch economic interests.

More importantly, the pure network quality indicators have difficulty assisting in the current degrowth situation of Schiphol Airport. The problem is that they give no guidance to remove the least net-economically important connections while keeping the most important ones. In this report, we have explored this broader approach to measuring network quality as a means rather than a goal in itself and attempted to integrate the cost of greenhouse gas emissions as an important part of environmental costs. Our study showed that about 30% of all direct connections fail to add directly to the Dutch economy. In comparison, about 10-15% of some very short-haul connections could be replaced by environmentally better transport modes.

One important reason to look at network quality is the expectation that a high-quality network will have significant economic effects. However, it should be noted that the quality of the network may have a different outcome if the environmental aspect is taken into the equation. To explore this, we first explored the relationship between network and trade volumes and found that this relationship is weak. We also explored direct revenues from O/D, inbound and transfer passengers, corrected for the impact on climate change are very promising for providing an economy-based network impact indicator. Also, such an indicator is based on real travel behaviour, rather than the supply of air travel. While the broader political goals of aviation policy (business climate, competitive position, and well-being of the population) are clear, this report argues the NQI_{GaWC} has problems serving these goals. For example, it could be possible that the most polluting network type may have the highest NQI_{GaWC}. Given that the number of seats in the NQI_{GaWC} largely follows the airline network strategy, the NQI_{GaWC} could promote the airline network strategy regardless of the consequences for the socio-economic development of the Netherlands.

7.2 Answers to the research questions

This study started with six research questions. Here, we provide a formal answer to each of these:

1. *What are common network quality indicators for air transport?*
   The air transport literature proposes many network quality indicators like the GACI (Global Aviation Connectivity Index), Betweenness and Degree Centrality. From a transport network technical perspective, these are more advanced than the I&W proposed NQI_{GaWC}. However, these do not necessarily account for the variation in the 'importance' of destination cities. Connectivity measures or centrality measures, such as degree centrality, are based on a specific node (airport) 's connections to other nodes. Eigenvector centrality considers the importance of the airports to which the node (airport) in question is connected. Still, this is based on connections and not necessarily the "economic importance" of a destination it connects to. An indicator that considers "pure" network characteristics prevents sample selection because no economically important destinations are chosen to show the link between being connected and the economy. Instead, this report brings forward the idea that a network quality indicator aiming to serve as a policy-informing tool for the wider policy economic and well-being policy goals must provide a strong correlation between network centrality and indicators for those socioeconomic goals.
2. *How does the I&W proposed NQIGaWC compare to indicators found in the literature?*
   NQI_{GaWC} has only a strong relationship with seat capacity (and flights) from AMS, but that is because seat capacity is part of the algorithm to calculate NQI_{GaWC}. GACI has no relationship with capacity, while Betweenness and Degree Centrality do have so. These latter two are better network quality indicators but pure from a transportation performance point of view. Though the NQI_{GaWC} does include an indicator for the importance of the destination to the Dutch economy, this indicator is one-sided and ignores both inbound and outbound tourism and travel. From our assessment, we find the NQI_{GaWC} does not relate unequivocally to the wider economic policy goals for air transport policies.
3. *What is the relationship between direct and indirect economic effects and network quality indicators?*
   This relationship is relatively weak for direct economic effects regardless of a correction for the climate costs of flights. We did not have the detailed data for indirect effects to do the calculations. Still, assuming that direct effects determine the indirect ones, we believe this will not fundamentally change the outcome.
4. *How can a network quality indicator inform a de-growth policy?*
   The I&W-proposed indicator cannot do so: when AMS grows, the accumulated NQI_{GaWC} grows almost linearly and vice versa. However, the ICII we propose, based on direct revenues, all transport modes and corrected for externalities, is much better able to distinguish between the highly varying economic values per destination with the least and most relevant destination cities, and it can easily handle the 50% of O/D-travel by other transport modes.
5. *5. What is the impact on results when integrating all international transport modes into one indicator?*
   The main effects are adding almost 50% of value to international connectivity, better relationships between connections and economic indicators and an overall better insight into the roles of different transport modes. Also, it helps to show opportunities for replacing flights with other transport modes without damaging the wider economy and significantly reducing the environmental impacts of international travel.
6. *What is the effect on results when incorporating environmental costs into the indicator?*
   Including externalities shows that certain flights, particularly those with high shares of transfer passengers, may negatively impact the Dutch economy. Further research would reveal if this outcome is consistent and would provide more concrete outcomes per airport connected through the network from Schiphol.

7.3 Recommendations

Overall, our main recommendation is to not use the I&W-proposed NQI_{GaWC} for policy-making concerning (de-)growth of Schiphol Airport but to develop a more policy-relevant indicator, an 'International Connectivity Impact Indicator' (ICII) rather than just the air transport network quality. The ICII should be based on direct revenues to the Dutch economy, include all transport modes and apply net-economic revenues corrected for externalities. The ICII much better informs policymakers and the industry on how growth or de-growth of air travel and other transport modes could best be arranged to have the best impacts on the wider economy. The reason for proposing the ICII is in the shortcomings of the proposed NQI_{GaWC} as outlined under the conclusions.
The following steps operationalize the ICII:

1. There must be a clear view of the indicator that describes direct revenues to the Dutch economy. After all, if the purpose of the indicator is to help formulate policy to improve the business climate, the competitive position of AMS and the well-being of the Dutch population, it must be clear how this will be measured. In the current report, direct expenditures were used. In line with the current guidelines for cost-benefit analysis, one could also look at total benefits. In the end, data must be available to measure the chosen indicator. This report has shown how expenditures can be used.
2. Various network centrality measures can be calculated. In this report, we estimated some of these measures. One problem was to gather the data necessary to perform such calculations. Another is that it tells you something about the efficiency of the air transport network itself to handle the travel demand, but not if that adds to the broader policy goals.
3. Therefore, we recommend establishing a correlation (or causal relation, if any) between the economic and network indicators.

The current report shows how to operationalise the three steps above. But more and better data is necessary to paint a complete picture. Particularly, data about the exact flight itineraries of current travellers to and from The Netherlands is needed. These data exist at the per-passenger level, including transfers and length of stay, but are not publicly or by contract available. Consider the example of Atlanta showing why better data and the ICII are necessary. Maybe Atlanta is not the most important destination for the Netherlands (in comparison to, e.g. New York), but the NQI_{GaWC} might give it a role less than some other cities. However, if we consider eigenfactor centrality, Atlanta would be very important because it is a major hub and, therefore, has a lot of connections with other North American cities. Direct connections from Amsterdam to all of these cities might not be worthwhile from an economic perspective, and certainly not if we factor in environmental effects. However, a connection to Atlanta means that the Dutch economy could still benefit from indirect connections to these other North American cities. Of course, whether other North American cities merit a direct connection is a function of total demand (should be sufficient) and whether a transfer in Atlanta would cause a detour (additional kilometres flown and thus environmental impacts) compared to a direct flight. But that will follow from the analyses. Similar arguments can be given for the air connectivity now offered to destinations already served by other, more sustainable transport modes.
To conclude, the ICII consists of a network indicator and an economic indicator and essentially tries to achieve the same as the NQI, namely to help policymakers formulate policy to enhance the business climate, competitive position of the Dutch economy and well-being of the population. More specifically, the ICII much better informs policymakers and the industry on how growth or de-growth of air travel and other transport modes could best be arranged to have the best impacts on the wider economy by looking at: i) how strong the relation between network connectivity in general and the wider economy is; and ii) which potential destinations contribute more to this relation than others.

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