The Missing Link between Coherence and Performance in Network Industries

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Overview

The institutional governance of many network industries has been undergoing fundamental developments over the last two decades driven by liberalization efforts and industry restructuring programs aiming at an improvement of the sector performance. Experience has shown that one of the factors explaining the performance of network industries is the degree of coherence between the technology of the network and the institutions that govern the network.

This paper examines the relationship between coherence and performance in network industries more closely and further develops the existing concepts. It is proposed that the missing link between coherence and performance is played by the concept of network constraints (capacity constraint, controllability constraint, interoperability and interconnection constraint). It is shown that the degree to which coherence is able to explain the performance of network industries depends on the sector-specific importance of network constraints. To get a better understanding of this dependency, several network sectors (electricity, gas, air traffic, rail, road, water, telecom, postal) are categorized according to the relevance of their network constraints.

At the example of the European electricity and air traffic sectors, it is examined in more detail how (in)coherence affects sector performance, and it is illustrated why coherence is getting increasingly important to maintain or even improve sector performance.

1 The coherence-performance framework for network industries

The initial coherence-performance framework for network industries as developed by Finger et al (2006) is illustrated in figure 1. In a first step, four basic system relevant functions are defined (interconnection, interoperability, capacity management and system management). Next, it is distinguished between technical and institutional coordination of the network and two main aspects of coordination (coordination mechanism and scope of control) are introduced. The framework then highlights that there is a certain degree of coherence between technical and institutional coordination, and it is argued that this degree of coherence has an impact on the performance of the network sector.

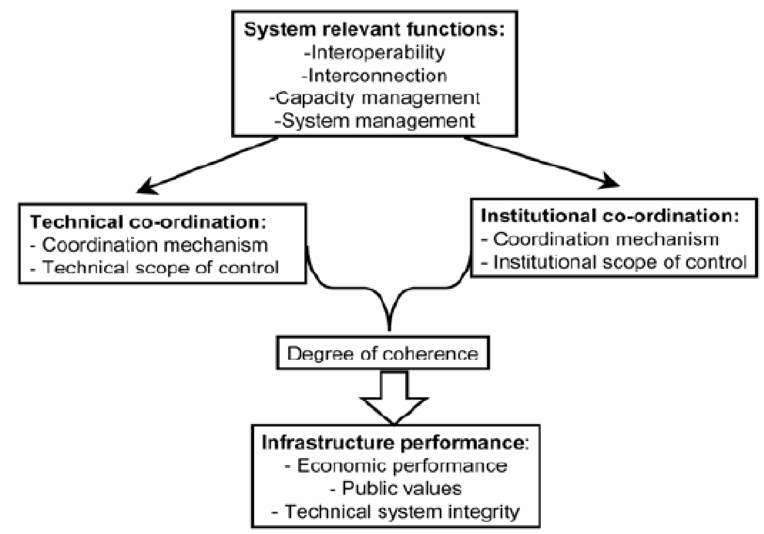

Figure 1: Coherence-Performance framework for network industries. Source: Finger et al. (2006).

2 Network constraints – the missing link to explain coherence

The original coherence-performance framework had two major shortcomings: First, it did not include a comprehensive definition of coherence and its categories, and second, it did not specify the mechanism by which the degree of coherence between institutional and technical coordination influences the sector performance. Hence, the framework was not able to systematically identify existing incoherences in a network sector and predict their impact on performance. In the following, we attempt to extend and refine the initial framework to make it more conclusive.

We propose that the **missing link** between coherence and performance is played by the concept of **network constraints**. Network constraints are limitations to manage the network created by the characteristics of the network technology. Based on this concept, the degree of coherence can be defined as the degree to which network constraints are incorporated in the institutional sector governance by means of network functions.

Similarly to the network functions, we define four basic types of network constraints: Interconnection constraint, interoperability constraint, capacity management constraint, system management constraint. Indeed, each of the network functions copes primarily with one of the network constraints, even though a network function can be affected by several network constraints. From a cross-sectoral point of view, we define the network constraints as follows.

1. Interconnection constraint: The ability to physically interconnect parts of the network may be limited.

2. Interoperability constraint: The ability to interoperate between parts of the network may be limited, even if a physical interconnection is established.

3. Capacity management constraint: By definition, any (physical) network has a limited transmission capacity.

4. System management constraint: There are two main aspects to system management: First, the *controllability* of the amount and direction of flows on a network may be limited due to physical properties or other restrictions. Second, *storability*, i.e. the ability of a network to store what it carries, may also be limited..

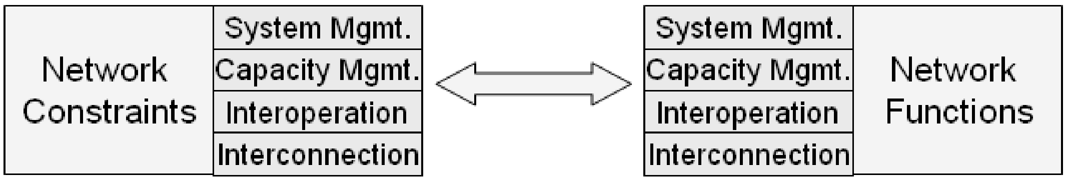

Figure 2: Network constraints and network functions.

The concept of network constraints applies to any network industry. However, the role that network constraints play is industry-specific and time-dependent. For instance, the controllability constraint is not as important in road transportation as it is in the electricity sector. The capacity constraint in the European air traffic sector 40 years ago was not as important as it is today.

Since the degree of coherence is defined as the degree to which network constraints are incorporated in the institutional sector governance by means of network functions, the extent to which coherence determines performance depends on the importance that network constraints play in the sector under consideration. In other words, the contribution of coherence in explaining performance is sector-specific. Apart from coherence, other technological and institutional factors contribute to explaining performance.
Figure 3 illustrates this finding and summarizes the ideas developed so far.

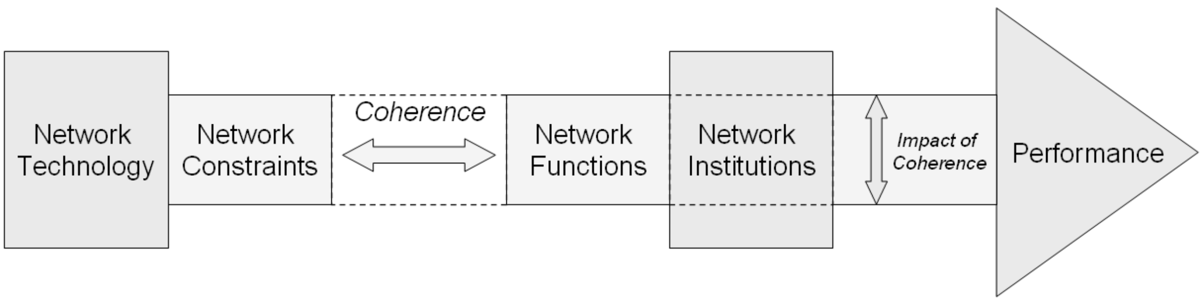

Figure 3: Coherence as an explanation factor of performance in network industries. The industry-specific importance of network constraints determines the extent to which (in)coherence can explain sector performance. Apart from

To get a first overview, the role of network constraints for several (European) network sectors is rated in the following table 1. The rating ranges from 1 (unimportant) to 2 (medium) to 3 (important).

		Network constraints Capacity	System Mgmt.		Interoperability	Interconnection
			Controllability	Storability		
(European) Network sectors	**Air traffic**	3	2	2	2	1
	Electricity	3	3	3	2	3
	Gas	2	2	2	3	3
	Postal	2	1	1	2	1
	Railways	2	2	1	3	3
	Road	2	1	1	1	3
	Telecom	1	1	2	2	1
	Water	1	2	2	2	2

Table 1: The role of network constraints in several (European) network industries. 1: Unimportant, 2: Medium, 3: Important (general, prelimnary values).

For instance, one of the main network constraints in the electricity sector is the fact that the network itself cannot store what it carries, i.e. it cannot store electricity[1]. Together with the requirement that generation and consumption have to be in balance at any time[2], this makes the storability constraints (as part of the system management constraint) in the electricity sector very binding. In other network sectors, the network offers a certain amount of storability, e.g. by queuing of vehicles on a road, circling of planes in the air (limited fuel!), storing of letters in a postal network etc. This relaxes the system management constraint in these sectors somewhat, though it still has to be considered.

Regarding controllability over direction and amount of flows, electricity flows obey physical laws and cannot be controlled actively by the system operators[3]. Other network sectors face a limited controllability, too. Airplanes can be deviated to a certain extent, but they remain bound to civil aviation routes (i.e. they cannot enter military airspace blocks) and fuel-dependant distance limitations. For other sectors such as road or postal, controllability may be less of a constraint.

Even within a network sector, controllability will depend on the technologies in use. In electricity, there exist two basic types of transmission technology: Alternating current (AC) and direct current (DC). With regards to controllability, they differ fundamentally: A DC line is fully controllable, while AC networks are highly interdependent and offer limited controllability. This explains why a DC line allows an easy institutional separation between the two network parts it connects (e.g. Nordic electricity system to continental European electricity system, or different regional electricity system in the U.S.), while an AC network requires a more intense cooperation between its governing institutions (e.g. cooperation between system operators in continental Europe).

A closer look at the air traffic, road and railway sectors reveals that they don't actually carry airplanes, trains, cars and trucks, but rather people and (perishable / non-perishable) goods. In

[1] There currently exist only few other possibilities to store electricity economically, such as through pump-storage hydro-power
[2] A deviation will cause frequency and voltage problems.
[3] New technologies such as phase shifters will offer a certain extent of control over electricity flows. This is an example of how technological developments can change the importance of network constraints

these sectors, the storability constraint is likely to be more important with regards to the transportation of people and perishable goods as compared to non-perishable goods. The distinction between perishable/non-perishable goods also applies to the postal sector. This explains partly why in these sectors, there often is a clear institutional distinction between people and cargo transportation and between normal and express transportation.

When it comes to interoperability, the more standardized a network sector is, the less important the interoperability constraint will become. In the European case, interoperability seems to be an issue mainly in international railways.

As most European countries are densely populated, interconnection is an issue in almost all of today's network sectors.

Finally, the capacity constraint is important in most modern network industries, too. For instance, both the European electricity and air traffic sectors are operating close to their capacity limits (see below).

3 Categories of coherence between institutions and technology

As was shown above, the appearance of network constraints is industry-specific. As coherence is established by the incorporation of network constraints in the network functions, it is reasonable to assume that there may exist several, industry-specific appearances of (in)coherence. From a theoretical point of view, the aim then is to build abstract categories of coherence that are of cross-sectoral relevance.

Indeed, this is what Finger et al. commenced in the initial version of their framework by introducing the coherence between scope (of coordination) and the coherence between coordination mechanisms (see figure 1). In terms of network constraints and functions, those two categories (mainly) belong to the coherence in system management. A network sector with limited controllability faces challenges with delineating individual scopes of control or the application of decentralized coordination. Figures 4 to 7 illustrate this observation at the example of the (European) air traffic and electricity sectors, the ones probably most affected by controllability constraints (see table 1): Both are highly interconnected infrastructures, yet coordination and control is substantially fragmented, leading to various performance issues[4].

Similarly, there exist coherence categories for the other pairs of network constraints and functions. As regards coherence in capacity management, one of the key questions is whether the institutional capacity management acknowledges the network (and its capacity constraints) in sufficient resolution (i.e. detail)? The debate on zonal and nodal electricity markets is driven by this coherence category.

[4] For instance, regional harmonisation of rules and procedures to improve sector performance is a major trend in both the electricity and the air traffic sector.

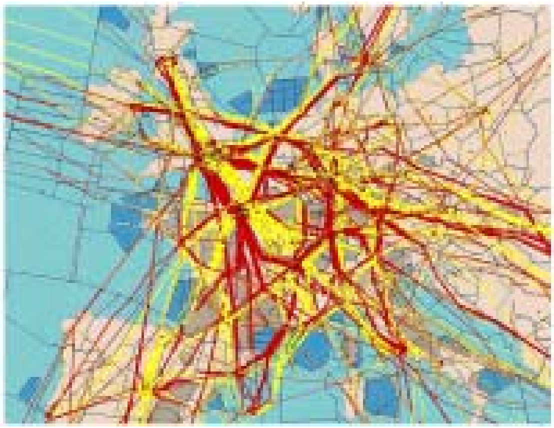

Figure 4: Major air traffic routes. Eurocontrol (2009).

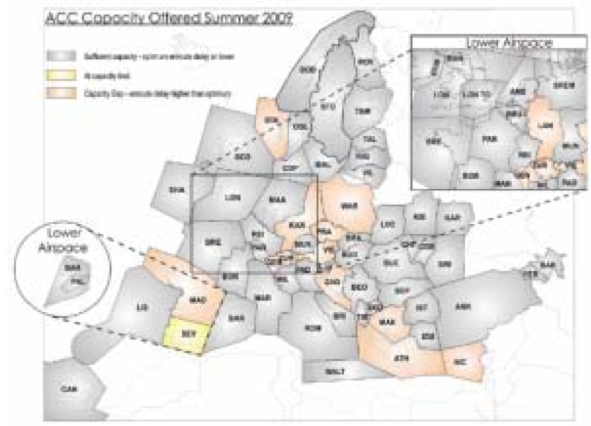

Figure 5: European air traffic control sectors. Eurocontrol (2009).

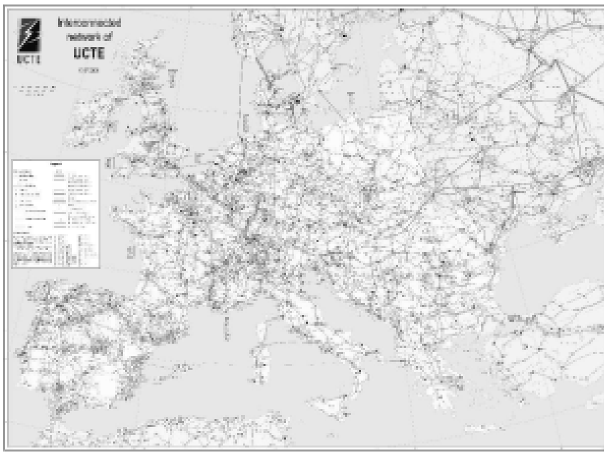

Figure 6: European electricity network. UCTE (2008).

Figure 7: Control zones primarily based on political borders. ENTSO-E (2009).

4 Evolution of network constraints

As long as network constraints are relatively unimportant (i.e. not binding), an incoherent institutional design doesn't limit sector performance – coherence simply doesn't matter (see figure 3). If however a network sector evolves such that network constraints become increasingly binding, an existing incoherence will lower performance. To maintain or even improve performance, coherence would have to be increased (of course, other technological or institutional factors could potentially be improved as well)

Again at the example of the European electricity and air traffic sectors, the figures 8 to 11 below illustrate some of the underlying drivers that have been aggravating network constraints and hence increased the impact of (in)coherence on sector performance: Increasing cross-border electricity flows (capacity constraint), increasing amount of variable wind power generation (system management and capacity constraint), and increasing air traffic movements (capacity constraint). Such developments often stimulate a co-evolution process, either by institutional changes (e.g. closer cooperation or integration of institutions[5]) or by technological innovation (e.g. decentralized power generation or new network technologies).

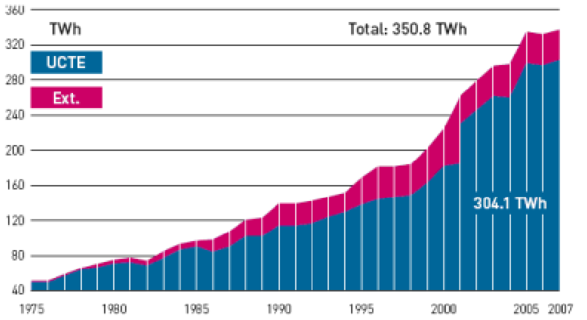

Figure 8: Increasing cross-border flows in the European electricity network, 1975-2007. ENTSO-E (2009)

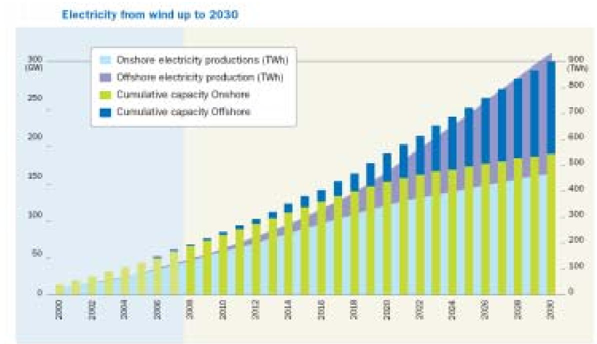

Figure 9: Expected volume of wind power connected to the European network, 2000-2030. EWEA (2009)

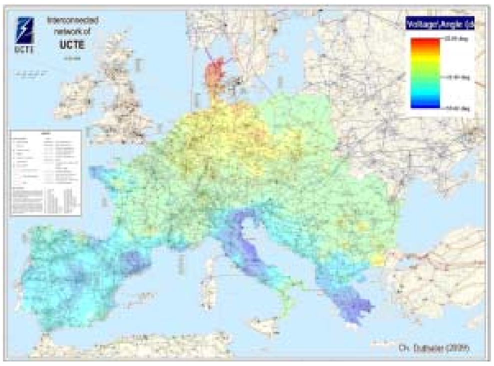

Figure 10: Illustration of dominant electricity flow pattern in Europe (from red to blue). Duthaler (2009)

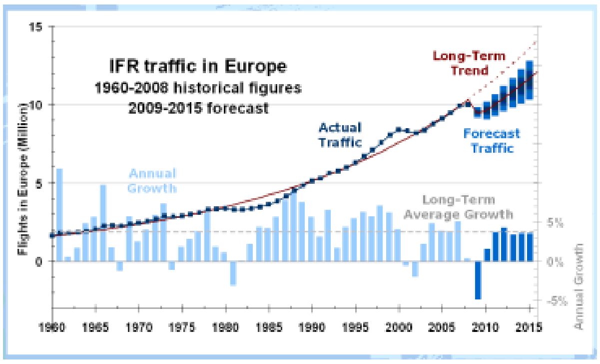

Figure 11: Increase in number of civil flights in Europe, 1960-2015. Eurocontrol (2009)

5 Conclusion

This paper concludes that the concept of network constraints (capacity constraint, system management constraint, interconnection and interoperability constraint) is the missing link both to define coherence in network industries and to explain performance in terms of coherence. While the concept of network constraint is sector-independent, their appearance and importance is sector-specific. Hence, coherence is sector-specific, too. Several network sectors have been described according to their network constraints, and major drivers behind the evolution of network constraints have been discussed. Further research is needed to identify additional categories of coherence and to refine the concept of network performance.

[5] Indeed, Eurocontrol's Central Flow Management Unit (CFMU) – introduced in 1996 – may be seen as response to improve coherence in air traffic capacity management. The CFMU optimizes air space capacity management at the European level taking into account airplane schedules and up-to-date airspace and airport capacities.

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