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What Happens to Facts After Their Construction? Characteristics and functional roles of facts in the dissemination of knowledge across modelling communities

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What happens to facts after their construction? Characteristics and functional roles of facts in the dissemination of knowledge across modelling communities[1]

Erika Mansnerus

Abstract
The core question addressed in this paper is: What happens to facts after their construction? The main contribution is to analyse the different practices of disseminating, circulating and cross-fertilizing model-produced facts about *Haemophilus influenzae* type b and *Streptococcus pneumoniae* bacterial infections and the preventive public health measures against the invasive disease forms. Through the analysis, the paper shows how facts become *characterised* in different utilizing communities. It elaborates an account of the *functional roles* of facts that are capable of shaping the knowledge practices in the receiving communities. These analyses suggest how facts can travel beyond their production sites to be used as evidence in other domains.

1. Introduction

Construction of scientific facts paved the way, slowly but inevitably towards the understanding of scientific work. This tradition, however, mainly paid attention to the activities that took place behind the closed doors of construction sites, such as laboratories.[2] We are often bound with the perspective given, i.e. we are so familiar with the narratives of construction and production or knowledge that we may have forgotten to observe what happens to knowledge, or in our story facts, once they are produced? But what happens to facts after their construction? How do they accommodate themselves into different

[1] Acknowledgements: This study is conducted in a Leverhulme Trust/ESRC funded project Nature of Evidence: How Well Do facts Travel? (Grant no: F/07004/Z) at the Economic History Department, LSE. I wish to thank Mary Morgan, Julia Mensink and my colleagues in the research project for their feedback on earlier versions of this paper. This research was presented in Biennial Conference of the Society for Philosophy of Science in Practice (SPSP 2007). I thank Martina Merz and Rachel Ankeny for their comments on that occasion.
[2] Cf. e.g. Latour and Woolgar (1979/1986); Knorr Cetina (1981).

environments? Do they change their identities or stay *stubbornly* where they are as “hard facts” validating scientific findings?

In this paper, I will explore the *characteristics* and *functional roles* of facts, providing a perspective that elaborates how practices (and communities) circulate and disseminate knowledge. First, by studying the characteristics of facts, we will learn how factual claims relate to the environment in which they are adopted and used. Moreover, characteristics of facts also tell us about the information content of knowledge claims and the possible changes in that content once facts are used and reinterpreted in different domains. Secondly, by studying the functional roles of facts, we will find how knowledge claims are incorporated into different practices and processes. By a “fact” I refer to knowledge claims that are generally accepted within a community and that can be reliably used by and acted upon other communities, or in other contexts, once they are documented.[3] It should be emphasised that a “fact” is not understood through its propositional character nor is it given a truth-value. Moreover, I exclude from the set of facts computational techniques and algorithms and consider them merely as templates.[4]

Characterisation thus refers to the way in which actors (e.g. modellers, epidemiologists, policy-makers) identify, recognise and acknowledge facts, and “address them” indirectly. In other words, the characterisation of facts is captured in the question: *How are facts seen?* My classification of facts is based on their use in a new domain. Characterisation brings one side of the answer to our quest of understanding how facts travel from their intended use in the production domain to re-interpretation in the use domain. Yet, this is not the whole picture. Characterisation is more or less a classification exercise, seeing

[3] Becker (2007:12) presents a community approach to facts: “[...] facts are only facts when they are accepted as such by the people to whom those facts are relevant”. However, this approach leaves aside the importance of usability and applicability of facts in both the producing or receiving communities.

something *as* something. Facts, however, may play different roles in the new domain, or function in different ways. In this respect, we may link them with the discourses that address the functions of models in scientific work.[5] Functioning in different roles in new domains of research, decision-making or application, means that facts may open new research questions, may carry and contain knowledge claims that might have been forgotten or otherwise ignored. They may store knowledge, mediate between different approaches, solutions, tasks, or even address materiality that is incorporated in the production and translation of facts.[6] These two sides, characteristics and functions, show (in a way) two sides of the coin; they tell us how facts become *identified* and *seen as*, and how they become used in new domains. Since the perspective in this story is that of facts, I have chosen to talk about characterisations and functional roles, which leaves the actors who characterise and use the facts in a side role. This may lead us to think that facts have been given *agency*; they are capable of challenging evidence, functioning in different ways, etc. However, this interpretation is mistaken – facts are observed as part of the social context in which they are either produced or applied. This context is normally a community of researchers (modellers, epidemiologists etc.) who recognise facts, adapt them from other scientific publications and apply them in their research. *Agency* is, hence, left with the individuals.

This study focuses on facts established in a set of infectious disease models built in different research communities mainly in the UK and in Finland (examining the population dynamics of *Haemophilus influenzae* type b and *Streptococcus pneumoniae* transmission, vaccination effects and herd immunity) and analyses their *characterisations* and *functional roles* within research and policy-making domains. The main question is: How are facts exchanged,

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[4] Cf. Humphreys (2004).
[5] Morgan and Morrison (1999).

accommodated, applied, or even ignored in the process of building and using infectious disease models for research purposes and policy-making? By increasing our understanding of the "movements of factual claims," we will learn from the nature of knowledge produced by modelling. This analysis develops two perspectives: first, it examines how facts are characterised in modelling communities. Are they chameleons, changing appearance in order to accommodate to a new environment? Or do we find thin, trimmed, or simplified facts? What if the facts in the new communities are "bloated" – enriched with added information? Secondly, it will look at the functional roles facts occupy in the new domains. The paper examines the capacity of facts to open new research areas, mediate different approaches, carry information to facilitate novel applications, or compare model-based findings.

In order to identify the characteristics of facts and trace their functional roles we will examine the case of a particular set of models generated from the parent 'Helsinki model.' This case pays special attention to the factual claims circulated across the models, therefore the main body of the research materials are publications.[7]

The case analysis is done in two phases. First, all publications reporting models on *Haemophilus influenzae* type b bacteria or *Streptococcus pneumoniae* published by the Helsinki modellers[8] before 2004 (n=8) were searched for cross-referencing[9] (42 citations) with the ISI Web of Knowledge resulting altogether in 50 publications to study. All the search results were studied to find the ways in which the cross-

[6] Cf. Latour's notion of inscription devices (in 1986).
[7] The study is also informed by previous research on interdisciplinary modelling practices at the National Public Health Institute, Helsinki, Finland during 2001-2004 and by the active participation in a course on infectious disease modelling organised by the London School for Hygiene and Tropical Medicine and Health Protection Agency, UK 2007.
[8] The Helsinki modellers are researchers (both junior and senior) who initially started the modelling research in a INFEMAT-project 1994 representing disciplinary backgrounds in mathematics/statistics, computer science, epidemiology.

referencing[10] was done. The findings indicated three different ways of referencing: First, by merely referencing in very general terms, as if only "acknowledging the existence of the group." Secondly, the referencing focused on the computational techniques or methods used or initially developed in the papers. Thirdly, the referencing was to "factual claims" that are treated as firmly based assumptions in the publications as, for instance, existing knowledge of the phenomena, model-based estimates and parameter values, and model-produced facts. This third category of referencing is in our focus. I have chosen[11] three published models (Auranen 1996, Leino 2000, and Auranen 2000), which were cross-referenced 21 times as examples to analyse in detail in this article, and, hence, ground my story of the dissemination of facts upon. The analysis carries a dual focus: both on the communities of practitioners and on the facts themselves. This means that the paper presents both the elaborate modelling practices and discusses the different forms of transmission in relation to the practices. Furthermore, the analysis reveals how facts are adopted in the utilizing communities and what kind of functional roles they occupy in these settings.

The structure of this paper is as follows. In section 2, I will discuss the way in which modelling practices spread facts by describing three different modes of dissemination and their relation to the networks formed in the course of these practices. This section, hence, brings a new insight into the prevailing studies that have mainly focused on the model-building practices, not on the ways in which facts are circulated

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[9] Cross-referencing means that an article by the Helsinki modellers was searched for the cross-citations in articles through the ISI Web of Knowledge in February-April 2007.

[10] Howlett (2008) studied how facts travel between two disciplinary communities: anthropology and economics by analysing citations in the disciplinary journals. He developed the notions of listening tree and talking tree to describe the processes of exchange.

[11] The choice is based on the observation that these articles were referenced both by the other studies in the Helsinki group or the wider Helsinki research community (those working for the same departments) and by various foreign studies on different topics (ranging from infectious disease studies to smoking).

across different models, or how models carry facts into novel domains (in research or policy-making). In section 3, I will analyse the characteristics of facts in the context of models. The idea is that some features of the facts are best addressed by describing, or characterising the fact in the new context. These characteristics tell us of the flexibility of facts and their capability to become adopted and accommodated in different contexts. Section 4 shows how the functional roles of facts change, how they facilitate the circulation and dissemination of the knowledge produced and reported. Section 5 discusses the underlying connection between factual evidence and practices and the instrumentalities that produce and disseminate them.

2. Insights into the communities: How does modelling circulate, disseminate and cross-fertilise facts?

How do facts spread across communities? What kind of observations can we make of the nature of factual evidence once it is *circulated*, *disseminated* or *cross-fertilized* beyond the initial production sites? This section elaborates these different modes of dissemination and discusses how they support the formation of social networks across collaborating research communities.

2.1. The Devil is in the Detail: Micro-practices of Modelling

Our current understanding of models[12] emphasises their capabilities to function in scientific work, mediate processes, and facilitate practices. Yet, models, built in interdisciplinary research teams, are not only primary objects of research but also facilitators for integrating knowledge from different fields of study,[13] in which *tailoring*[14] describes

[12] We address models as being representations of a phenomenon under scrutiny or as tools and instruments for investigation. Along with analysing the functions of models as objects of research, we have a growing interest in understanding the practices that shape them. Cf. Morgan and Morrison (1999).
[13] E.g. Mattila (2006).

integrating modelling practices: it means building, using and applying models for specific purposes, in particular answering specified research questions in interdisciplinary communities. Even though these studies have enriched our understanding of the increasing importance of modelling in science, and given us vivid accounts of the heterogeneity of models as research objects, the question of generalisable evidence produced by modelling has not yet received proper attention in current studies. More precisely, models have been represented in their local contexts as the *primary* interest of analysis, however, our focus is on the facts produced in the models and disseminated via them to different domains. This is studied by analysing the *characteristics* and *functional roles* of facts in relation to the specific modelling practices.

In order to understand the dissemination of factual claims and their meaningfulness in complex simulation models in infectious disease studies, one needs to be familiar with the details of the epidemiological phenomena and the scope of the research questions guiding the modelling practice. I will first introduce the main characters of this story, namely *Haemophilus influenzae type* b bacteria (Hib) and *Streptococcus pneumoniae* (Pnc) and contextualise their importance from the public health perspective in order to focus on certain facts about them.

Haemophilus influenzae type b (Hib) bacteria is also known as *Pfeiffer's* bacillus according to its discoverer Robert Pfeiffer who was able to isolate the germ in 1892.[15] Hib colonises the nasopharynx and is transmitted in droplets of saliva. Hib is capable of causing severe and oftentimes life-threatening disease among small children (and adults). These diseases include *bacterial meningitis*, *septicemia*, *otitis media*, *arthritis*. Hib vaccination development started once the first strains were demonstrated in the serum of patients. In the 1970s the first line of

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[14] Mattila (2006).
[15] A detailed story of understanding Hib transmission is presented in Mattila (2008).

vaccines, so called *polysaccharides,* were introduced. To improve their efficacy, *conjugate* vaccines were developed in the 1980s and implemented as part of national immunisation systems 1985 in the USA, 1986 in Finland and 1992 in the UK.[16] This resulted in a dramatic decrease in the reported cases of Hib disease in the respective countries.

Streptococcus pneumoniae (Pnc) was identified as an organism in 1881 by Luis Pasteur and George Stenberg. Similarly to Hib, Pnc colonises the human nasopharynx. Its polysaccharinde capsule and the fact that Pnc has over 90 different strains made the vaccine development difficult. Currently conjugate vaccines have been introduced to the national programmes in the USA and in the UK. However, EU-wide vaccination strategies are yet to be refined.[17] Both these bacteria, Hib and Pnc, cause meningitis, Pnc being the leading cause of the disease. Approximately 400-700 000 deaths are caused by Hib alone and 3 million serious cases of Hib disease occur yearly among children aged 4-18 years in the world.

The public health facts that can be addressed by modelling can be translated into the following research questions that were studied by the Helsinki modellers in relation to Hib:

> "Does vaccination alter the age distribution of Hib disease and incidence?"
>
> "Does natural immunity vanish from the general population, which would indicate the need to revaccination?"
>
> "How high must the vaccination coverage be in order to prevent Hib disease in population?"

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[16] The difference between these two vaccines lies in their molecular structure. The efficacy of *conjugates* is partly a result of the fact that it does not only protect against Hib diseases but it also reduces the carriage of Hib and hence circulation of Hib diminishes in a population, which has a positive effect on *herd immunity*.

[17] Pebody et. al. (2005).

In the following analysis of the ways in which models produce and distribute factual knowledge, these public health questions are the starting point for model-building.

There are different ways of addressing the dissemination of factual knowledge across research communities and their models. However, our story aims at the rather detailed level, in order to reveal how the facts are integrated into models in the different phases of the process. A general frame is an adaptation of the stepwise procedure of modelling. This frame is developed to trace the ways in which facts function through the dissemination and circulation process across different context. The stepwise procedure[18] means that modelling process can be divided into different 'sub practices' that are relatively universal for the model-building process. It captures all the phases from formulating the initial model question, through the design, quantification, validation to prediction and decision-making based on modelling. Through this we can understand, not only how the practices shape the modelled phenomena, but also how they facilitate the exchange of knowledge claims: facts produced and applied in the process. I use these steps, to introduce the modelling process as an environment to monitor the exchange and circulation of facts. This reveals two hidden aspects in modelling. First, the facts delivered through one step in the modelling process, could be received in another step or phase during the process. This tells us that there are different ways to identify and apply factual claims in models. Secondly, the analysis of the micro-practices enables us to see the importance of models in the dissemination of facts. For example, the laborious phase of model quantification (parameterisation[19]) becomes easier, if one is able to apply a given estimate established in another model.

[18] This paper applies an approach presented in Habbema et. al. (1996).
[19] In climate modelling, parameterisation is a more commonly used term than quantification, both terms refer to the same set of practices.

In a closer analysis, we are able to define three different "modes of dissemination." First, and mainly within and among[20] the Helsinki-models, we can talk about *circulation*, a form of dissemination that allows returning, revising, and reusing the model-based findings and facts. Secondly, *dissemination* can be defined as the one-way distribution and spread of modelled facts. Dissemination is the practice of "scattering or spreading" the facts and findings. Thirdly, *cross-fertilization*[21] is a form of dissemination in which facts or model-based findings 'feed into new models' and potentially result in "observable fruits": outcomes for which these facts prove beneficial. In the following figures (Figure 1 & 2), I will present the two initial models built in Helsinki (1996 and 2000), in order to show the different outcomes and facts of these models, and describe the modes of dissemination. This allows us to see also how other findings, techniques and methods are disseminated as "templates" along with the facts. A full table that summarises the analysis of facts for all the three parent, or source, models (1996, 2000, and 2000) is presented in the appendix. They are named as the Good-night kiss model (GNMK, 1996),[22] the Dynamics of natural immunity model (DNIM, 2000) and the Transmission of Pneumococcal carriage model (TPCM, 2000). Furthermore, *circulation* and *cross-fertilization* of facts provide an insight from the *practice* point of view on the *characteristics* and *functional roles* of facts. By this, I mean that circulation and cross-fertilization explain why certain facts are "picked up" and utilised in the new contexts and domains. They are, in a way, "reproductive, fertilizing" modes of dissemination.

[20] This observation is, to some extent limited by the data searches that have followed the spread of Helsinki models to other communities.
[21] As a biological term it means to "fertilize by pollen from another flower or plant". Also used as stimulating development of something by exchanging ideas or information.
[22] In section 2.2., GNKM is also presented as a source model in a figure that shows how models facilitate the formation of research networks.

In brief, this story tells us about the generalisation of model-based knowledge through the different modes of dissemination, it gives us a unique perspective on how this happens inside modelling procedure within which facts are delivered and received, and it allows us discuss the main question: How do practices move facts around?

Let us first illustrate the modes of dissemination with the following graph. The facts estabilished in the 1996 GNKM model were *circulated* and *cross-fertilised* in two further models (1999, 2004), built at a later stage. Modelling techniques were disseminated as a template, acknowledged only as a possible approach in O'Brien et. al. (2003).

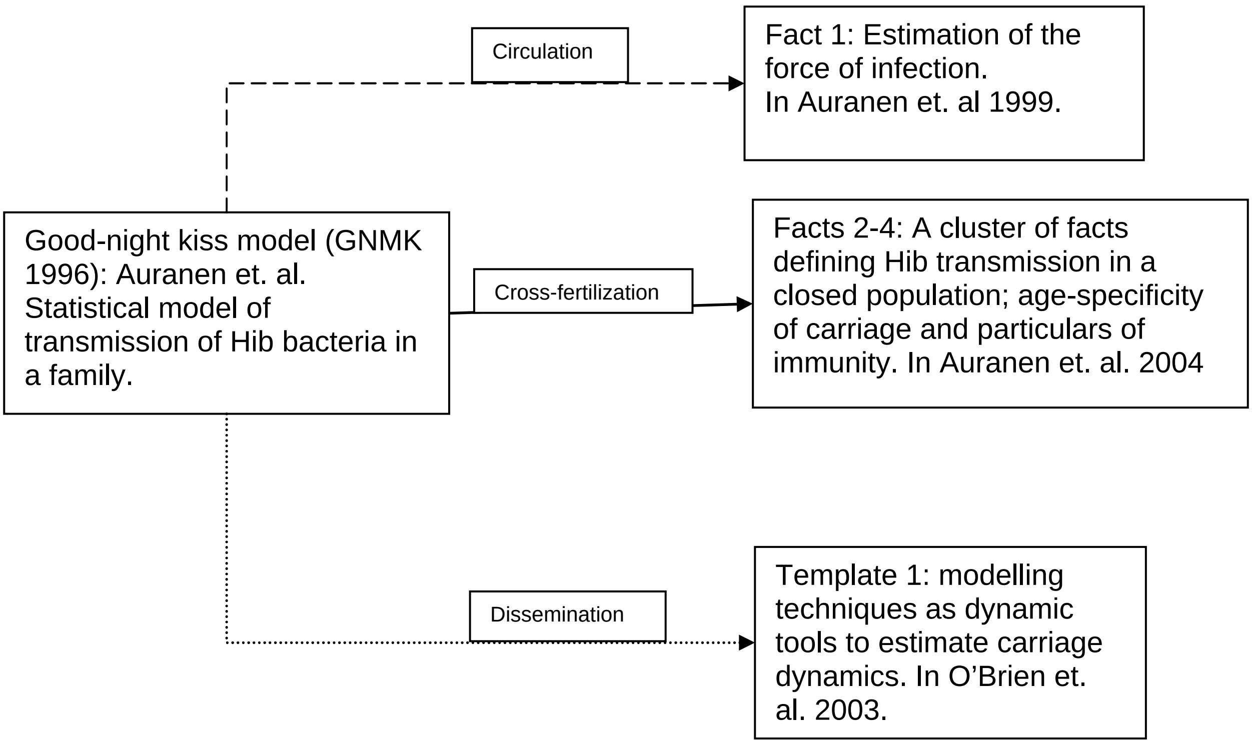

Figure 1: Illustration of three modes of dissemination of facts and templates from the Good-night kiss model (1996).

Figure 1 shows how facts (1-4) and a template of modelling techniques were disseminated from the parent model (GNKM) to three other models, over a longer period of time. The estimate for the force of infection was circulated to a later built model (1999). The mode is described as circulation, since the adoption of that estimate actually required returning to the parent model (1996) in order to detect how to calculate it in a novel context. Cross-fertilization, which is a form of dissemination when model-based facts prove beneficial to novel “outcome” facts, took place when a cluster of facts about transmission were adopted into a complex simulation model. These facts fertilized the model and enabled simulation-based outcome facts to appear as a result.

We may observe similarities in the modes of dissemination in our second example, presented in figure 2, below:

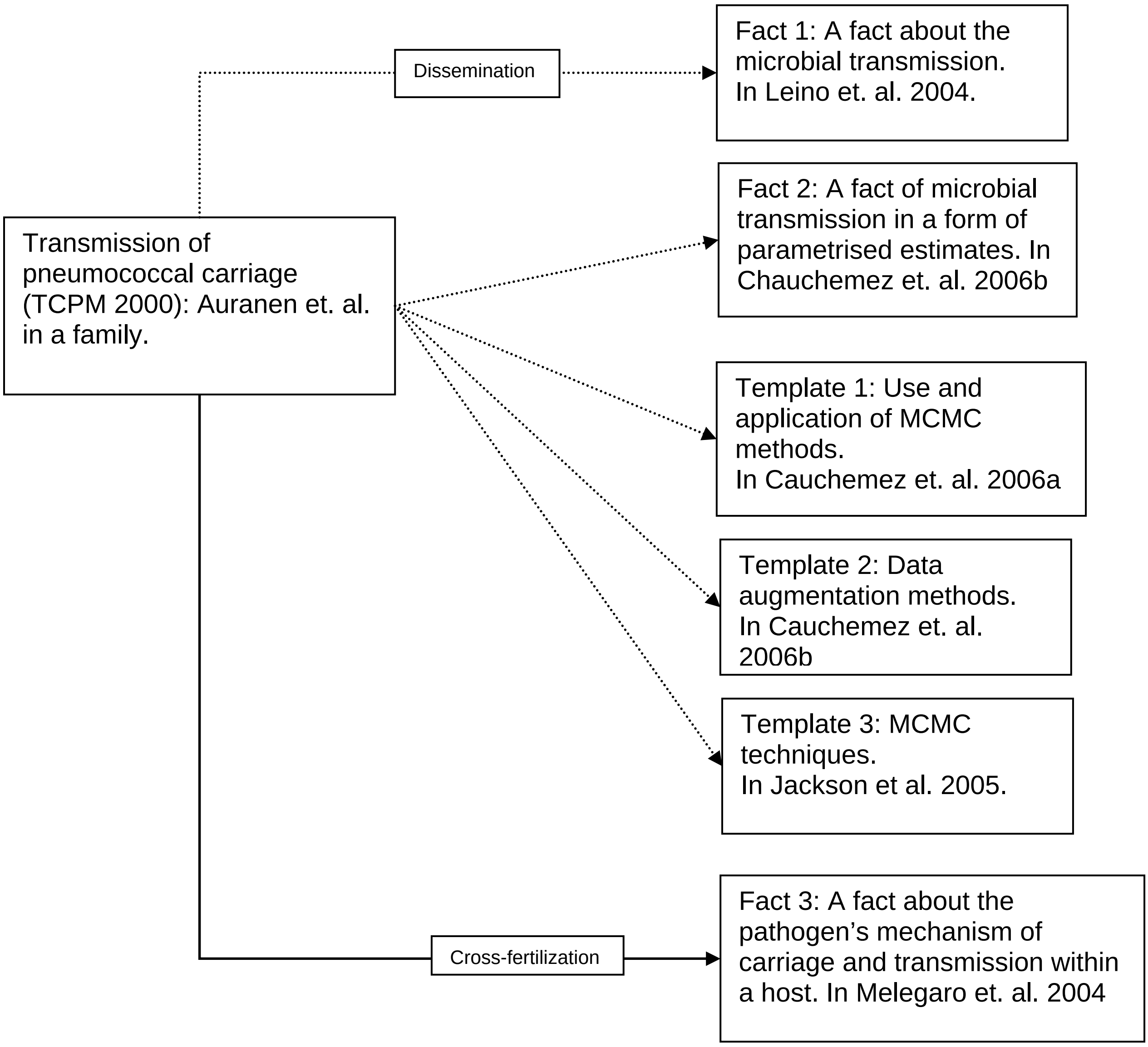

Figure 2: Illustration of how facts and templates are disseminated from a pneumococcal carriage model of 2000.

This example shows that both facts and templates are disseminated to new contexts. Interestingly, we also observe that the adoption of the fact 3 results in new output facts in terms of defining the within host transmission dynamics in Melegaro's model (2004).

On the basis of the graphs (Figure 1-2), we have studied the three different modes of dissemination: *circulation*, *dissemination,* and *cross-fertilization*. We have also noticed that the model (TCPM 2000) presenting a latent Markov process model for transmission of *pneumococcal* carriage was a rather influential one in disseminating the templates to different contexts. However, one should bear in mind that PnC studies, especially around 2003, were of special interest since the conjugate vaccines had been launched to the market, and many EU countries were shaping their national vaccination policies[23]. But it is not only these factors that facilitate dissemination. The model documented techniques were designed to overcome problems of missing data. Especially data augmentation in the Pnc and Hib models were primarily targeted for estimation purposes, since the data were collected well before the researchers aimed at conducting the modelling exercise. Data augmentation led to the development of latent Markov chain models, MCMC sampling methods etc. Sometimes the development of techniques travelled mainly as an anecdote, observation that these techniques were shown to be efficient in a specific question.

However, the analysis shows us that models are capable of disseminating both the findings and facts established in them, and the computational methods, algorithms and techniques built into them. In other words, both facts and computational templates[24] are disseminated from models and by models. Leaving methods and templates aside, we will focus on how facts are disseminated across modelling communities and beyond by conceptualising their potentially changing *characteristics*

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[23] Cf. Pebody et. al. (2005)

the different communities attribute to them, and by exploring the *functional roles* they take in the new contexts.

Next, we will explore through an example, how different research communities identify and recognise 'factual' claims, what kind of status they give to them, and how they use them. Does an epidemiological 'fact' become a statistical estimate in the process? This is a way to see how different pieces of evidence actually nurture different communities, and enable them to enhance their research goals, while the facts carry the trace of their origin with them.

2.2 Networks of Dissemination

Facts seem to facilitate the formation of social networks. The primary adoption of a fact furthers the mutual contact between different modelling groups. Dissemination of facts facilitates and enhances personal relations among the researchers. As one interviewee told me, a referee process pointed him to the facts published in a Helsinki paper on Hib models. This, then, encouraged him to meet the modellers in a forthcoming conference and share ideas. Networks seem to be built upon the epistemic primacy of disseminated facts. As we observed in the previous section, models were capable of carrying *traces* of facts, when the methods and techniques were disseminated across the communities and domains of research.

To get a detailed idea of the ways in which facts spread across different models to create networks, I provide the following example of the early transmission model, the Good-night Kiss Model (GNKM, 1996), which serves as the origin of the facts. From this model, the facts are disseminated to other Hib and Pnc studies, referenced by different research groups, and they even end up in a WHO vaccination policy report to promote Pnc vaccines. The following illustration shows the

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[24] Humphreys (2004) argues that a template is a rather universal set of equations, methods or techniques that is capable of adapting from one field to another.

referential ties between the models, ties that facilitate and maintain the *dissemination* of facts. However, this illustration does not tell us how the facts were identified, used, acknowledged in the different models – in other words, the *characteristics* and *functional roles* are yet to be explored.

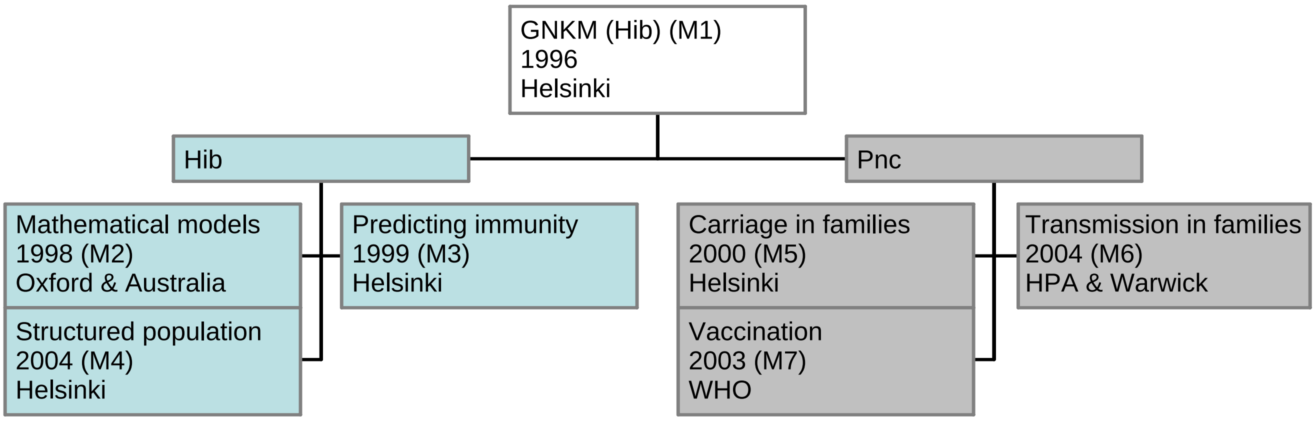

Figure 3: Illustration of the "family-tree" of the parent Helsinki model (GNKM 1996) to other models on Hib and Pnc. The names are the names of the models that use and apply the facts; the location refers to the geographical site of the modelling group or the origin of the report in which the fact was used. This illustration shows how research networks emerge from the dissemination of facts established in a single model.

Let us study in detail how the facts from a single model were disseminated and how they facilitated the emergence of research networks. The Good-night kiss model (GNKM) (M1) was published 1996 and it is an individual-based model that was built to describe asymptomatic Hib infection in a family with small children. This model was designed to estimate family and community transmission rates simultaneously. It was fitted with datasets collected in Finland 1985-86 and in the UK 1991-92, in both cases just before the Hib immunisation programmes were introduced. The model was used to study the spread of Hib via good-night kisses among family-members with small children.

The model itself[25] represents the beginning of the modelling collaboration, since it was the very first of the set of models built during the Helsinki project.[26] In the following years, the Helsinki group, built a set of Hib (M3, M4) and PnC (M5) models in which facts established in GNKM were *circulated* and *cross-fertilized*. For example, a cluster of Hib transmission facts (age-specificity of carriage, duration of immunity, dynamics of transmission) were fed into the 2004 model (M4) that simulated transmission in a structured population (which means that the age-structure is clearly specified in the model). But the facts also reached and travelled beyond the Helsinki group. Efforts establishing links to other researchers thus created a research network: the 2004 model on transmission in families (M6), built by a group at the Health Protection Agency and Warwick University, utilised the fact that the course of Hib infection follows the S-I-S pattern in a population in their PnC model to structure the similar kind of dynamics. Moreover, a fact of transmission rate established in GNKM was adopted in a set of models (M2) published by researchers from Oxford. This detailed story of a singular model and its capability to disseminate, circulate and cross-fertilize facts across other modelling communities gives one perspective on how research networks are formed: they rest on the circulated, factual knowledge often prior to formal collaborational ties.

In summary, this section showed us how modes of dissemination of facts and computational templates form communities and shape their practices. This helps us to shift the perspective to facts, and analyse what happens to them in the receiving communities. How are they characterised and identified? What functional roles do they adopt?

[25] Discussed in Mattila 2006a.
[26] The Helsinki project was a multidisciplinary modelling project during 1994-2003 at the National Public Health Institute with collaborating partners from the University of Helsinki and the Technical University of Helsinki.

3. Characteristics of facts

Character is oftentimes linked with innate nature of things – even the everyday use of character in sentences such as “she’s got quite a character” implies that there is something special in the person herself. However, we may take another look, and consider “character” as something that is given by the community – character as socially defined property of persons and things. This shift in the perspective helps us to be more precise on what we mean by “characteristics of facts.” While observing the characteristics, our focus is on the *changes* we attribute to the characteristics of facts in the course of the various modes of dissemination.

Could we consider the *characteristics* in terms of social recognition and identification of facts, metaphorically as their *social identity*? Increasing the conceptual framework may have its own downside, but let us play with the idea of a *social identity of a fact*. The basic assumption is that modellers, either in the building or application practices, identify facts according to their usefulness and applicability. They recognise the knowledge claims and re-interpret, adopt, shape or ignore them in due course of their work. Social identity,[27] as a metaphor, relies on the socio-cultural understanding of the concept: It is way of behaving or becoming oneself in a community. Our metaphor of the social identity of a fact should be understood as a concept that underlines the importance of the community interpretation, use, application, recognition and adoption of factual claims. These different practices directed towards the facts are the practices by which we *characterise* them or *identify* them. Hence, the community, in a crucial way, shapes the factual knowledge.

[27] A social identity of a person relies on a dialogical relation to other people. For example, if we follow Vygotskian ideas of child development, we learn that in a dialogical relation with the community, a child develops skills of using tools, material and symbolic means (language) and therefore becomes part of the community. (Vygotsky 1978).

The environment, in which a fact is acknowledged or accommodated, can also initiate changes in the character of a “fact.” The information content of the fact may also vary. Hence, the characteristics of facts can be presented in two axes (see Figure 4): Flexibility in relation to the environment or content, and in terms of their ‘weight’. These axes are discussed in terms of *stubborn* and *chameleon* facts and *enriched* and *simplified* facts. Let us first explore the characteristics presented in Table 1.

Table 1: Summary of the analysis of the characterizations of facts.

Characterisation and definition of a fact	Example	Description of a fact	Why the specific character?
Stubborn[28] A fact that is resistant to change. May require some auxiliary measures to be operationalised or quantified in a model.	Cluster of facts of Hib transmission.	“Transmission of Hib occurs through asymptomatic carriers. Most episodes of Hib carriage pass without clinical symptoms, and only in rare cases does carriage proceed to invasive disease.”(2004)	A ‘fact’ that repeats the cluster of claims about Hib transmission, and although it links that knowledge to the 1996 model, it actually relies on general epidemiological understanding of Hib transmission dynamics.
Chameleon A fact that accommodates well in a new environment. A fact that easily or frequently changes its appearance – or its “colour”.	A fact that exemplifies the dynamics of transmission (in a Hib immunity model, Auranen 1996).	“[As in Auranen 1996], we set the transition from C to S to be dependent on a constant recovery rate.” (Melegaro 2004)	A fact of the dynamics of transmission pattern (SIS-model) describing the immunity, was accommodated in a Pnc study (Pnc follows a similar but not identical immunity dynamics as Hib). It was easily adopted and modified to fit Pnc.
Enriched A fact that becomes bloated (i.e. swollen with something extra, like a swamp	Estimates of the force of infection.	“In the previous study on Hib carriage in families (1996), the force of infection is	A fact, or estimate of the force of infection was enriched in the destination (1999)

[28] Also used by Daston (1992).

that is swollen from liquid). A fact that is enriched.		probably related to different nature of data. In that article, data on antibodies was not included.”	with the data from antibodies and the importance of estimating the force of infection in relation to all details of transmission dynamics was discussed (carriage, antibody levels, cross-reactive bacteria).
Simplified A fact that is simplified, or slim, capturing only the very plain core of the fact.	Estimates for a Hib transmission rate in a family.	“For example, Hib transmission rate is thought to be greater within families whose members have experienced Hib disease.”	A fact, a sophisticated estimate for a transmission rate in a family was simplified into a factual claim ‘thought to be greater’, even though it was originally a numerical estimate.

As table 1 summarises, *stubbornness* characterises a fact that is resistant to change during its travels. In our story, the cluster of Hib transmission facts are exemplary representatives of *stubborn facts*. Why is that? From the epidemiological studies[29] we learnt that reaching the understanding of Hib transmission dynamics is a rather challenging task. The details and specificities required thorough understanding not only the pathogen but its circulation in specific age-groups, its capability to hide in asymptomatic carriers, and its incapability to enforce permanent immunity. Due to these challenging facts, it also became the major player in the models in order to estimate the vaccination effects, to optimise the herd immunity threshold and to produce evidence for recommendations for the implementation of the expensive conjugate vaccines. *Stubbornness* is a way to describe this cluster of facts as unchangeable, inflexible, and, perhaps, robust.

[29] Explored in Mattila (2008).

The contrary characters to the *stubborn* are *chameleons*: facts that are easily accommodated to new environments. A model structure, as a part of the model design process, is an important step in modelling practices. It is a phase in which one needs to incorporate the knowledge of the infection dynamics, the population structure and transitions among these "pools." At the same time the structure will feed into the quantification, and each transitional step will be denoted with parameters, which lead to the estimation process. The SIS structure, which carries the fact of the transmission pattern of Hib and the status of immunity caused by the infection, was adopted by a group that studied the transmission of Pnc. They clearly adopt it by saying that: "As in Auranen, we set the transition from C->S to be dependent on a constant recovery rate" (Melegaro et. al. 2004). This fact could be seen as a *chameleon*: it is taken, modified, and adjusted to accommodate the Pnc transmission and what is known of it. Even though it was not strongly modified in the new context, its character as a *chameleon* is supported with the idea that it is easily adjustable from its old into a new context, which in this case is the transition from Hib to Pnc.

These characteristics, the *stubborn* and the *chameleons* are related to the environment, either they resist the relocation or they accommodate well. We have, however, also observed that some facts are characterised in terms of the information they carry with them: are they circulating a slim, simplified piece of knowledge from one model to another? or are they enriched and bloated with they weight of the information they disseminate?

Estimation of the force of infection (the rate of infectivity) is an example of enriched, bloated fact. In its origin, it was a clearly defined, model 'output' fact carrying a numerical value of the estimate. Its source was the simple transmission model (GNKM), and later it was enriched with other aspects in later models: Impact of antibody levels, cross-reactive bacteria and other details of the transmission dynamics were added into it – bloating it and giving more weight to its factual content.

In another example of this kind, we find a model examining long term persistence of immunity after vaccinations also adopted the estimates for the dynamics of natural immunity as a valid 'fact' of prediction upon which they were able to build the vaccination model[30]. In a similar way, a model-based prediction was taken as a fact into a model on *Pneumococcal* carriage[31]. Interestingly though, this estimate was re-enforced by observed data-based trends in Hib infections studied in England and Wales[32]. What can we conclude from these adaptations of the immunity decline rate, as the model-laden facts? In the case of the vaccination study and the Pnc carriage, the decline rate is an enriched fact, taken into a new context and bloated with information from the existing literature and datasets.

An example of a simplified 'fact' is a model-based estimate for a Hib transmission rate in a family. Even though this rate was the outcome of a highly sophisticated transmission model, it was used only as a comparative reference point, without a connection to the numerical estimate it had in the original model. It was slimmed and simplified, and yet circulated to new contexts. We can summarise these examples in figure 4, below:

[30] Mäkelä (2003).
[31] Leino (2001).
[32] McVernon (2004).

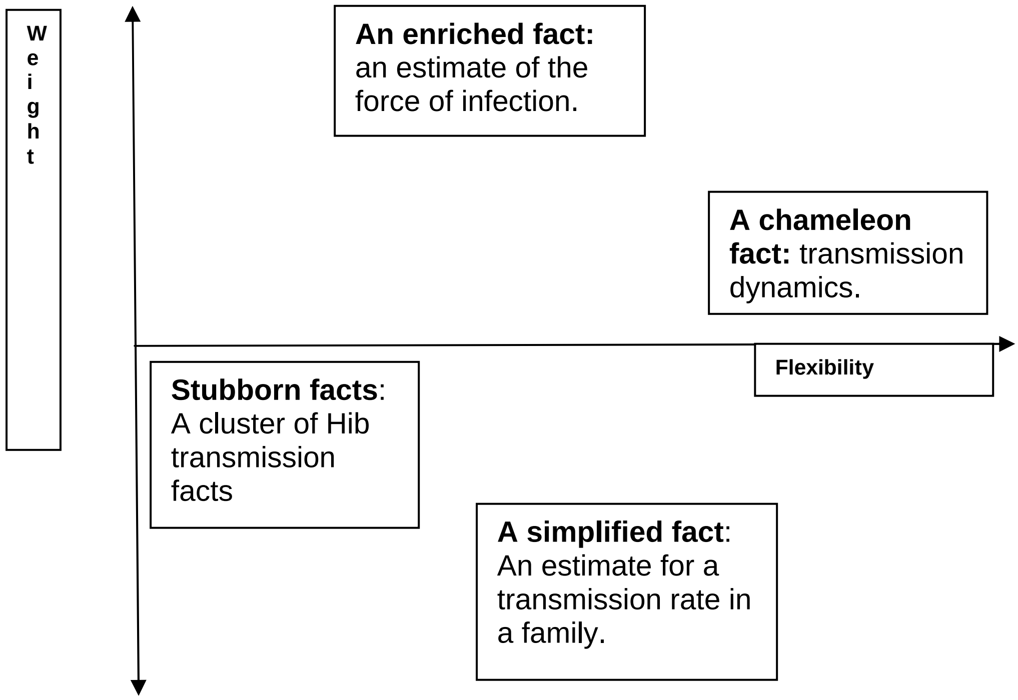

Figure 4 illustrates the two axes: "information content" and "ability to change", and locates the different characteristics of facts accordingly.

These characteristics of facts provide a new dynamics to understand the ways in which factual claims are disseminated across models to other modelling and policy-making processes, from infectious disease epidemiology to non-communicable diseases. First, on the axis of environmental relations, we learned that *stubborn* facts either resist change or require fine-grained micro-practices to operationalise them into models. We also observed that *chameleons* "change their colour" and form in order to accommodate well in new models. Secondly, we noticed that the information content might be enriched or simplified in the course of circulation of facts.

These two observations remind us that the factual knowledge is subject to the ways in which it is used, interpreted, and modified in the contexts to which it is disseminated from the source of origin, i.e. from the production site. facts become characterised through the interpretations that accommodate them well, or keep them as they are, in the new sites.

4. Functional roles of facts

Characteristics of facts told us how knowledge claims become identified and accepted in different communities. However, we are keen to explore in detail, how facts function within and beyond their construction sites. This perspective allows us to elaborate a dynamic account of evidence that goes not only beyond the opening of “the black-box of production”, but also to the further use of evidential knowledge. Our perspective, hence, shifts the focus from the production of knowledge to its utilisation, where I will show what kinds of functional roles are given to the facts, and how we can define them and conceptualise these different functional roles.

In the detailed story above into how facts travel through the micro-practices of modelling, we learned how the different phases or steps in the procedure are dependent on various inputs, either brought into the model by studies conducted in the modelling group or from existing knowledge. Modelling is an iterative exercise, in which a modeller seeks to find the balance between realistic enough description of the phenomena, the amount of information available and the sampling scheme of the data[33]. Once the modelling inputs are accepted the inferences drawn from them are reasonably stable. This need for ‘input facts’, i.e. estimates, parameter values, and data, opens the door to analyse what kinds of functional roles the different facts are given across various modelling practices. How do facts actually function within and across models?

In the following table (Table 2), I will describe the functional roles and analyse the examples of the roles played by circulating facts. The functional roles form a triad: *broker* opening new areas of research;

[33]Auranen (1999: 16)

mediator reconciling and mediating different approaches, and *container* storing information.

Table 2: Functional roles of facts: their definitions and examples.

Functional role and its definition	**Description of the 'fact' within the case**
Broker (example 1) A fact that is capable of creating and negotiating a space, opening new lines of research, asking new questions, expanding ongoing processes.	Fact: The fact states that immunity to Hib is not permanent. This fact is established in a model structure for the immunity model on Hib originally described in Auranen 1996. In Auranen 2004 it functions as a *broker* since it documents the original variation of immunity to Hib in the model structure and incorporates it with further knowledge on different factors influencing transmission (that were studied in Auranen 2004). "Transmission is influenced by the recurrent nature of carriage acquisition, and the typical clustering of Hib carriage in a family and day-care settings." (Auranen 2004: 947)
Broker (example 2)	Fact: The fact shows Hib transmission rate in a closed population taking into account the basic dynamics (structure of the family, children's relatedness in peer groups). The fact functions as a *broker*, since it opens new research in Pnc studies by giving the direction (transmission in a family) and the estimated rate. "Following the work by Auranen and colleagues, the model considers transmission of Pnc within the household" (Melegaro 2004: 435).
Mediator (example 1) A fact that reconciles two approaches, techniques, methods, datasets, parameter values; intervening 'fact' that effects reconciliation.	A fact to describe the dependency between individuals and close contacts in transmission dynamics. In Auranen 2000, it functions as a *mediator* between Hib and Pnc studies by reconciling how to express the basic dynamics. "When modelling disease transmission, it is important to acknowledge dependency between binary sequences of individuals with close contacts. Because of this dependency, the states of Markov process in a family are actually vector of ones and zeros, which simultaneously denote the infection state of all family members" (Auranen 1996).
Mediator (example 2)	A fact to describe indirect effects from Hib conjugate vaccines (reduction in carriage and boosting of immunity levels). It states that conjugate vaccines are able to reduce colonization of Hib in nasopharynx. The fact functions as a *mediator* since it bridges the gap between Hib and PnC studies, mediates between childhood and adulthood studies. In Lexau (2005): "How much vaccine coverage is needed for indirect effects remains a key question. A model evaluating this in Hib conjugate vaccine showed

	that much of the decline in invasive disease could be attributed to indirect effects of the vaccine, even at relatively low levels of vaccine coverage.”
Container (example 1) A fact that stores its information, not necessarily knowing where and when it will be picked up or referred to.	A fact that predicts the decline in natural immunity of Hib. In McVernon (2004), it functions as a *container*, since the fact stores the information, in this case the numerical value of the decline rate. “Our data shows that the reduction in opportunities for boosting natural immunity has resulted in a decline in specific Hib antibody titres among adults.” McVernon 2004.
Container (example 2)	A fact that estimates the protective level of maternal antibodies to protect an infant (under 6 months of age) against Hib infection. It functions as *container*, since it is picked up as a useful fact in a study that estimates levels of antibodies to Tetanus toxoid, Hib and Pnc. “The low but presumably protective titers found in the unimmunized infants might be explained by persisting maternal antibodies on the one hand and emerging cross-reactive protective antibodies on the other.

The analysis presented in the table identifies three types of functional roles of facts: *brokers*, *mediators* and *containers*. *The broker* functions by initiating new research, opening up, expanding and challenging aspects of the given research topic. It is capable of changing the contexts (from one pathogen to another). The broker functions, for example by circulating the transmission rates or facts embedded in the model structures into new production contexts. Yet, such facts often synthesise what is already known enabling the broker to show the need for new explorations, new studies, or perhaps new applications. How does the *broker* function, if we examine it in detail?

The major finding in the Good-night kiss model, a ‘fact’, was to establish the transmission rate among family-members in relation to the size and age-structure. This fact was later adopted in a simulation model (Auranen 2004) as a way to understand transmission and build the fine-grained simulation model.

> “Transmission is influenced by the recurrent nature of carriage acquisition and the typical clustering of

> Hib carriage in family and day-care settings."
> (Auranen 2004: 947.)

In this case, the way in which GNKM circulates the 'facts on transmission' actually the provides the basic model structure. In 2004 model this is further modified and used and hence that 'fact' is recognised as a *broker*, since it stimulates more research, more specifications and negotiates a new space by doing so. The main shift was that the transmission in a tight family-structure was now considered in different small-groups (day care setting and school).

The mediator functions between different approaches, problems, domains by enhancing reconciliation. In our analysis, *mediators* were facts that increased the reconciliation between the epidemiological data derived from surveys or experimental settings[34] and the model. As our example pointed out, the fact described the effects of conjugate vaccines for Hib and reconciled the lack of knowledge on conjugates' effects on immunity in the case of PnC in adults. Hence, it functions not only between different types of pathogens but also between different groups in the studied population.

The Dynamics of natural immunity model (DNIM) as a source model studied the impact of conjugate vaccines and their capability to reduce natural immunity in a population. Such vaccines had the property of reducing carriage of Hib in vaccinated populations, which may have resulted in waning of natural immunity also among the unvaccinated. This model was developed upon a hierarchical Bayesian model to predict duration of immunity to Hib (Auranen 1999) and it was based on data from follow-up measurements of Hib antibody data in Finland (gathered during a polysaccharide vaccine efficacy trial in the 1970s). This model provided the core of the immunity model implemented in 2004, into the individual-based population simulation model (Auranen 2004), and interestingly though, the dynamics of natural immunity model functioned as a “shared memory” repository during the simulation process. On the basis of the interactional data, I observed that while some of the Helsinki models functioned as repositories or storage spaces, as described by the Helsinki modellers, it was not the whole of the model that was used as such, some particular facts were adopted or adjusted in the simulation model. What were then the facts adopted from this model? The Dynamics model (DNIM), for example, established the ‘fact’ that vaccination affected the sub-clinical infections occurring between vaccinations and the antibody measurement. The fact of antibody concentration dynamics was taken precisely as it is from this model, partly because determining the parameters is laborious process in modelling, and partly because this model was successful in estimating the relation between the decline of antibodies and the force of infection in a population. This fact was also adopted into a model that studied the impact of cross-reactive antigens (pathogens that circulate in the population and boost immunity). Hence, the ‘fact’ of natural immunity functioned as a *container*, storing and carrying facts of the immunity rates, and other details that influenced the process.

To sum up, the *functional roles of facts*, as analysed in this section, underlines two aspects of the model-based evidence. First, it shows that the facts are rarely taken into the new contexts without some effect: opening up further research, providing mediating solutions that have been tested and acknowledged in other domains, or containing information, parameter values, or estimates. In some examples, the origin of the fact was clearly expressed and openly linked with the other groups’ work. Secondly, by elaborating the *functions* of facts, we learn why it is crucial to establish links between different models. Composing a model is not a simple task, in order to gain a reliable model and to be able to produce evidence for the chosen research questions, one needs

[34] E.g.. observations from serological data.

to master the techniques, understand the particulars of the available data, and to address the field or domain that applies the model-based facts. Facilitating this process by relying on estimates established in other studies or comparing the model-derived rates with the empirically validated ones, are all part of the *iterative* process of modelling, which establishes factual evidence of the phenomena for further applications. Therefore, understanding the locality of modelling and the central focus of their roles in scientific investigations, should be extended towards the uses and applications of the knowledge they have produced. By elaborating the *functioning roles* of facts, we have seen how facts travel out beyond original models and their production sites.

5. Conclusions

This study has shown how *characteristics* and *functional roles* of facts include or implement the social context to the knowledge claims. Hence, we have observed, how facts were elaborated, contested and negotiated in and through the various social networks and communities of practice.

It seems that models are capable of establishing knowledge that the community thinks of loosely as facts and these facts are adopted into different research frameworks. Such facts are, for example, the specific immunity levels, (maternal antibody titres), the average duration of carriage, age-specificity of carriage, or the rates of exposure to cross-reactive bacteria. Interestingly through the manipulation practices facts become characterised. Their usability and generalisability depend on the practices in which they become adopted. These facts may later be studied or contrasted with those from clinical studies, which means that they are compared with existing data, and given further confirmation.

What do we learn from the dissemination of facts? First, we have identified three modes of dissemination: *circulation*, *dissemination* and *cross-fertilization*. However, the mode of dissemination does not define the characteristics or the functional roles of facts. They are merely means of understanding how knowledge claims are spread across research and policy-making communities. Furthermore, our story of functional roles and characteristics of facts reveals something of the nature of evidence produced in epidemiological models and later used in policy-making.

Our interest was to understand how were facts exchanged, accommodated, applied or ignored in the process of building and using infectious disease models for research purposes and policy-making. However, we may wish to address this question in somewhat broader terms, in terms of the nature of evidence. What did we learn from evidence and its dissemination through our analysis? We are familiar with the distinction between evidence *of* and evidence *for*[35] , but this may not be enough to uncover the path from production to use and applications. It may seem, at least to some extent, that evidence *of* something is nurtured in the production domain and it turns into evidence *for* something when entering use domain. Yet, the boundaries between these domains may have been too ‘clear-cut’, perhaps ignoring the different domains of use and application – and perhaps allowing us to “black-box” the concept of evidence. Our analysis took a different take on these questions by focusing on facts and by elaborating the different modes of dissemination that showed us how they travel across different domains in terms of their applicability and usability. Furthermore, by studying the ways in which the receiving communities *characterised* facts we learned that only some facts maintain their character as a stable and *stubborn*, whereas most were prone to change: either in terms of their information content or adaptation to the new environment. So, in our account facts travel across different communities that shape and re-interpret them, to use them rather as evidence *of* as well as evidence *for* a decision-making processes. In a

[35] In a similar way as Fox Keller (2000) discusses models *of* and models *for*.

similar way, the exchange of facts from within the production domain to use and to apply them can be elaborated in terms of their functional roles. When facts are seen as *brokers*, *mediators* or *containers*, we are subscribing to a more dynamic account of evidence: observing what kinds of functional roles are given to facts in different domains. So, our efforts to understand the ways in which facts are disseminated across various domains help us to evaluate not just model-based evidence but its usability and applicability in further producing and using domains.

Appendix: The full table summarising the modes of dissemination in relation to the three source models. Examples illustrated in the Figures 1-2 are on italics.

From: Source of a 'fact'	**To: Destination of a 'fact'**	**The 'fact' that travels**	**A 'template', i.e. modelling technique or model structure**	**Mode of dissemination**
Model 1 (GNKM): Auranen, K et. al. 1996: Statistical model of transmission of Hib bacteria in a family	*Auranen et. al. 1999: A hierarchical Bayesian model to predict the duration of immunity to Hib*	*Estimation of the force of infection.*		*Circulation: Estimate is derived from the 1996 model.*
	Auranen et.al. 2000: Transmission of pneumococcal carriage in families: a latent Markov process model for binary longitudinal data	A fact that when modelling disease transmission, one needs to acknowledge the dependency between individuals with close contacts. [Method of modelling transmission in terms of binary relations / Markov process].		*Circulation*: Specificity of disease transmission reported in 1996 model is revised in terms of expressing it as a binary process.
	Auranen et. al. 2004: Modelling transmission, immunity and disease of Hib in a structured population	*Specific cluster of facts of defining: Hib transmission dynamics in a closed population, age-specificity of Hib carriage and special features of Hib immunity model.*		*Cross-fertilization: Particular facts established in 1996 model are fed into the 2004 simulation transmission model. '1996 model-based facts are cross-fertilized and the simulation model produces new 'fruits'.*

	Coen et. al. 1998: Mathematical models of Hib	Hib transmission rate in a family	Hib transmission rate in a family	*Circulation:* A model-based fact of transmission rate is taken to the new Hib models.
	O'Brien et. atl. 2003: Report from a WHO working group: standard method for detecting upper respiratory carriage of Streptococcus Pneumoniae	.	*Modelling techniques as tools to estimate carriage dynamics.*	*Dissemination: To acknowledge the potential usefulness of modelling techniques for PnC studies.*
	Melegaro et. al. 2004: Estimating the transmission parameters of pneumococcal carriage in households	Transition between S-I-S.		*Dissemination*: A model structure is adopted into a new context.
	Ashby, D 2006: Bayesian statistics in medicine: a 25 year review		MCMC techniques.	*Dissemination:* MCMC techniques used in Auranen 1996 were referenced in Ashby as a statistical method.
Model 2 (DNIM): Leino et. al. 2000: Dynamics of natural immunity caused by subclinical infections, case study on Hib	Auranen et. al. 2004: Modelling transmission, immunity and disease of Hib in a structured population	Estimates of natural immunity based on the presented immunity model (2000: 954).		*Dissemination*: Estimate adopted from 2000 model and implemented in 2004 transmission simulation model.
	Leino et. al. 2002: Hib and cross-reactive antigens in natural Hib infection dynamics: modelling two populations	Force of infection.		*Circulation*: Estimate for the force of infection re-used in

	Mäkelä et. al. 2003: Long-term persistence of immunity after immunisation with Hib conjugate vaccine	A model estimate to predict antibody resistance after an initial response to Hib PS (polysaccharide vaccines).		*Dissemination*: Particular estimate value adopted to give numerical form to the immunity response on polysachharides.
	Leino et. al 2001: Pneumococcal carriage in children during their first two years: important role of family exposure	A fact about carriage depicted a closed population.		*Circulation*: Carriage model re-used in a PnC study.
	McVernon et. al. 2004: Trends in Hib infections in adults in England and Wales: surveillance study	Prediction of decline in natural immunity.		*Dissemination*: Decline rate from Leino 2000.
Model 3 (TPCM): Auranen et. al. 2000: Transmission of pneumococcal carriage in families: A latent Markov process model for binary longitudinal data	*Leino et al: 2004: Indirect protection obtained by Hib vaccination: analysis in a structured population model*	*A fact about the microbial transmission.*	*A fact about the microbial transmission.*	*Dissemination: 'Factual' claim of transmission.*
	Eerola et.al. 2003: Joint modelling of recurrent infections and antibody response by Bayesian data augmentation	An estimation of average duration of carriage.		*Dissemination*: Carriage estimate for Pnc.
	Cauchemez et. al. 2006: Investigating Heterogeneity in Pneumococcal Transmission: A Bayesian MCMC Approach Applied to a Follow-up of Schools		*"An estimation of epidemiological parameters from field data has gained renewed interest in communicable diseases with the use of MCMC methods".*	*Dissemination: MCMC methods (article grounds their development among other approaches to Auranen 2000).*

	Bartolucci 2006: Likelihood inference for a class of latent Markov models under linear hypotheses on the transition probabilities		The latent Markov model was introduced by Wiggins for analysis of longitudinal data and has been successfully applied in several fields (medicine/ Auranen).	*Dissemination*: MCMC methods elaborated in a latent Markov model.
	Cauchemez et. al. (2006): S-pneumoniae transmission according to inclusion of conjugate vaccines: Bayesian analysis of a longitudianl follow-up in schools	*An estimation of transmission parameters.*	*An estimation of transmission parameters; data augmentation.*	*Dissemination: Both a model-estimate of transmission (both models study PnC transmission) and of data augmentation methods (elaborated in 2000 model in a form of a latent Markov model).*
	Cauchemez et. al. 2004: A Bayesian MCMC approach to study transmission of influenza: application to household longitudinal data		Data augmentation method.	*Dissemination*: Data augmentation methods (elaborated in 2000 model in a form of a latent Markov model).
	Melegaro et. al. 2004: Estimating the transmission parameters of pneumococcal carriage in households	*Longitudinal carriage studies to gain insight into the pathogen's mechanism of carriage and transmission within hosts.*		*Cross-fertilization: Particularly the carriage estimates were adopted from 2000 model to Melegaro 2003 model.*
	Cooper et. al. 2004: The analysis of hospital infection data using hidden Markov models		MCMC methods.	*Dissemination*: MCMC methods, to model similar (but not identical) kind of data on a different pathogen.

	Jackson et. al. 2005: Use of strain typing data to estimate bacterial transmission rates in healthcare settings		*MCMC techniques.*	*Dissemination: MCMC methods to develop estimate of bacterial transmission rates for Pseudomonas aeruginosa and Staphylococcus aureus.*
	Mannan et. al. (2003): Latent mixed Markov modelling of smoking transitions using Monte Carlo bootstrapping		Latent MCMC model.	*Dissemination:* MCMC techniques used in the latent model of smoking transitions.

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