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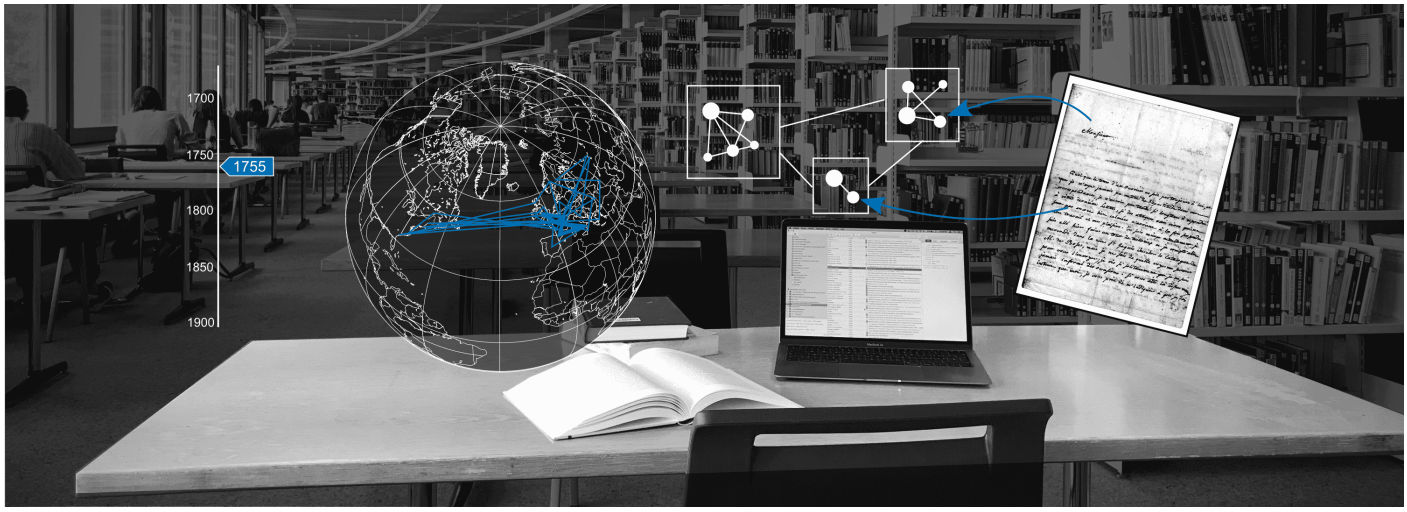

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The Journal of HISTORICAL NETWORK RESEARCH

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"Taking time seriously": an empirical approach to an American merchant network at the end of the 18th century

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Abstract Network analysis tends to produce snapshots of structures that can seem permanent, unaffected by time or change. Nonetheless, time matters in network history, and the observation of its effects is an issue. This paper explores ways to assess the evolution of an American merchant network at the end of the eighteenth century, building on a database of transactions recorded in Levi Hollingsworth's account books. Here, I develop a comparative analysis of five successive networks, using a mix of classical and more innovative network metrics. Specifically, I question the stability of merchant networks in their composition and overall structure. I establish that, despite an intense turnover of members, they remained stable in their organization over time.

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1. Introduction

Following numerous theoretical works that stress the importance of studying time in historical networks, this paper consists of an empirical approach to the topic. From an experimental perspective, it offers a series of techniques to capture the effects of time on five instances of an 18th-century American merchant network. The goal is to go beyond a purely visual comparison of snapshots of graphs and elaborate on some metrics that allow us to explore the evolution of networks over time. In this paper, time is conceived as a duration and a series of different events that can chronologically affect different structures (in this case the structures of trade)[1]. Focusing on time thus means studying the way a merchant network could change based on its inner and outer dynamics.

Time matters in historical networks, and network historians are more and more starting to "take time seriously", as Claire Lemercier has advocated.[2] In her seminal paper from 2015, she demonstrates how the notion of change is both essential and hard to capture in network analysis. The study of network dynamics represents an active field in network theory and its applications.[3] Attempts have been made to model networks over time.[4] For their part, historians also show an

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1 On the existence of different conceptions of time, and the importance of developing time-conscious historical approaches, see John R. Hall, "The Time of History and the History of Times." *History and Theory* 19, no. 2 (1980): 113–31; Lynn Hunt, *Measuring Time, Making History* (Budapest: Central European University Press, 2008); Justus Grebe, "Time in History," in *Geschichtstheorie am Werk,* 07/12/2021, https://gtw.hypotheses.org/1764 (Access Date 11/09/2022).

2 Claire Lemercier, "Taking time seriously. How do we deal with change in historical networks?" in *Knoten und Kanten III. Soziale Netzwerkanalyse in Geschichts- und Politikforschung* ed. Markus Gamper, Linda Reschke and Marten Düring (Bielefeld: Transcript Verlag, 2015), 183–211.

3 For a synthetic view of the field, see Petter Holme and Jari Saramäki, "A Map of Approaches to Temporal Networks," in *Temporal Network Theory,* ed. Petter Holme and Jari Saramäki (Cham: Springer, 2019), 1–24. See also Patrick Doreian and Frans N. Stockman (ed.), *Evolution of social networks* (Amsterdam: Gordon Breach, 1997); Patrick Cohendet, Alan Kirman and Jean-Benoît Zimmermann, "Émergence, formation et dynamique des réseaux. Modèles de la morphogenèse," *Revue d'économie industrielle* 103 (2003): 15–42; Gueorgi Kossinets and Duncan J. Watts, "Empirical analysis of an evolving social network," *Science* 311 (2006): 88–90; Patrick Doreian *et al., Understanding Large Temporal Networks and Spatial Networks: Exploration, Pattern Searching, Visualization and Network Evolution* (Chichester: John Wiley & Sons, 2014).

4 Petter Holme and Jari Saramäki (ed.), *Temporal Networks* (Berlin: Springer, 2013).

increasing interest in these questions, as can be seen from the various works presented during the HNR+RESHIST Conference in the Summer of 2021.[5]

There is an appeal for historians to tackle the issue of time within historical networks, which comes with specific notions that must be considered, such as duration, or temporal scale.[6] The concept of duration refers to the length of a relation (how should we determine how long a relation lasted?)[7] There are several ways of capturing duration in temporal networks, especially in attributing a higher intensity to the longest of the relations.[8] Temporal scale refers to the level of analysis in a temporal network (should the evolution of the network be tracked second by second, month by month, decade by decade etc.).[9] Taking time into consideration also alters the definition of transitivity. In static networks, when A is linked to B and B to C, we assume that there is a path between A and C (through which information can flow, for instance). In temporal networks, the transitivity of this connection is only possible if the two relations coexist, and especially if A–B is anterior to B–C.[10]

Beyond this set of preliminary definitions, historians also need to determine what questions they wish to answer through temporal network analysis. Relying on works in sociology (which focus on ego-networks, but which can be trans-

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5 Among others, Martin Grandjean, Matteo Valleriani, and Emmanuel Mourlon-Druol have advocated this notion. More explicitly, Matthew Hammond gave a talk about "Modelling longitudinal data: dynamic networks and research question-led variable datasets – the case of medieval royal households" and a software presentation was dedicated to "PAOHVis: Analyzing Dynamic Hypergraphs with Parallel Aggregated Ordered Hypergraph Visualization", a tool in part aimed to visualize hyperlinks over time (which relies on the work of Paola Valdivia, Paolo Buono, Catherine Plaisant, Nicole Dufournaud and Jean-Daniel Fekete). This list is not exhaustive.

6 On these notions, see Petter Holme and Jari Saramäki, "Temporal networks," *Physics reports* 519, no. 3 (2012): 97–125.

7 On this topic, P. Holme and J. Samramaki question the distinction between "contact sequences" (each network relation is instantaneous) and "interval graphs" (each relation has a duration that can be determined). See Petter Holme and Jari Saramäki, "Temporal Networks as a Modeling Framework," in *Temporal Networks,* ed. Petter Holme and Jari Saramäki (Berlin: Springer, 2013), 1–14.

8 Vincenzo Nicosia, "Graph Metrics for Temporal Networks," in *Temporal Networks,* ed. Petter Holme and Jari Saramäki (Berlin: Springer, 2013), 15–40; Alain Barrat and Ciro Cattuto, "Temporal Networks of Face-to-Face Human Interactions." in *Temporal Networks,* ed. Petter Holme and Jari Saramäki (Berlin: Springer, 2013), 191–216.

9 Rajmonda Sulo Caceres and Tanya Berger-Wolf, "Temporal Scales of Dynamic Networks," in *Temporal Networks,* ed. Petter Holme and Jari Saramäki (Berlin: Springer, 2013), 65–94.

10 On this question, see Petter Holme and Jari Saramäki, "Temporal Networks as a Modeling Framework," in *Temporal Networks,* ed. Petter Holme and Jari Saramäki (Berlin: Springer, 2013), 1–14; Ramona Roller, "Modeling time in letter correspondence networks of the European Reformation: beyond snapshots towards temporal paths", *HNR Lunch Lectures,* (15th of April 2021). (https://www.youtube.com/watch?v=TD0bBokSF6g).

lated into other forms of networks), C. Lemercier stresses the importance of links (their persistence over time, transformations of their content), nodes (their presence, changes in their attributes), and the overall network structure.[11] This paves the way for narratives concerning the growth (or decline) of networks, the effects of the structure on the relations through time, and identifying the most important nodes.[12]

Finally, there is the issue of the implementation of these questions: what should we compare in order to monitor change, growth or correlations over time? Models have been developed to take time into consideration. Among them, the Siena (actor-based stochastic) model is a major reference.[13] Aside from these models, there is a second approach that relies on visualisation in order to compare time slices.[14] Nonetheless, many of the researchers referring to this approach note to the difficulty associated with the visualisation of changing structures. Ramona Roller, in her presentation of the Pathpy project, shows how interesting it can be to move beyond merely comparing snapshots.[15] Once the definition of a time scale is coherent with the data, I advocate for the method of comparing time slices. In this paper, I develop several examples of metrics that permit the comparison of networks over time, as well as monitoring the effects of time on these structures.

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11 Claire Lemercier, "Taking time seriously. How do we deal with change in historical networks?" in *Knoten und Kanten III. Soziale Netzwerkanalyse in Geschichts- und Politikforschung* ed. Markus Gamper, Linda Reschke and Marten Düring (Bielefeld: Transcript Verlag, 2015), 183–211, who uses an example from Scott L. Feld, J. Jill Suitor and Jordana Gartner Hoegh, "Describing Changes in Personal Networks over Time," *Field Methods* 19 (2007): 218–36.

12 Petter Holme and Jari Saramäki, "A Map of Approaches to Temporal Networks," in *Temporal Network Theory,* ed. Petter Holme and Jari Saramäki (Cham: Springer, 2019), 1–24.

13 On this model, see Ainhoa De Federico de la Rua, "L'analyse longitudinale de réseaux sociaux totaux avec Siena," *Bulletin de méthodologie sociologique* 84 (2004): 5–39; Tom A. B. Snijders, Gerhard G. van de Bunt and Christian E. G. Steglich, "Introduction to stochastic actor-based models for network dynamics," *Social networks* 32, no. 1 (2010): 44–60. For examples of its application: Emmanuel Lazega *et al.,* "Réseaux et controverses: de l'effet des normes sur la dynamique des structures," *Revue française de sociologie* 49, no. 3 (2008): 467–98; Claire Lemercier and Paul-André Rosental, *The Structure and Dynamics of Migration Patterns in 19th-century Northern France,* 2009, halshs-00450035v3.

14 Ulrik Brandes, Natalie Indlekofer and Martin Mader, "Visualization methods for longitudinal social networks and stochastic actor-oriented modeling," *Social Networks* 34, (2012): 91–308; Emily Buchnea, "Transatlantic Transformations: Visualizing Change Over Time in the Liverpool-New York Trade Network, 1763–1833," *Enterprise and Society* 15, no. 4, (2014): 687–721; Claudio D. G. Linhares *et. al.,* "Visualization of structure and Processes on Temporal Networks" in *Temporal Network Theory,* ed. Petter Holme and Jari Saramäki (Cham: Springer, 2019), 83–105.

15 Ramona Roller, "Modeling time in letter correspondence networks of the European Reformation: beyond snapshots towards temporal paths", *HNR Lunch Lectures,* (15th of April 2021). (https://www.youtube.com/watch?v=TD0bBokSF6g).

This paper exemplifies how such methods can be implemented by applying them to merchant networks from the end of the 18th century. These merchant networks are drawn from the account books of Levi Hollingsworth (1739–1824) for the years 1785, 1786, 1787, 1791 and 1795[16]. The network had already existed since the 1770s and persisted for decades into the nineteenth century. In this paper, time does not have a beginning nor an end, but is merely a series of changes or continuations in an existing structure. It is also discontinuous, since we do not have a full set of networks between 1785 and 1795. Still, my sample allows for comparisons in the short term and within a longer series (the four years between 1787, 1791 and 1795).

Hollingsworth was an important flour dealer in Philadelphia, the largest city in the United States at the time of this study.[17] As a flour dealer, he maintained strong relations with backcountry millers and farmers, large urban and Atlantic traders, and producers in the American South or the Caribbean.[18] He was one of the many merchants that helped to connect rural consumers to the Atlantic world of goods.[19] Most of his partners were concentrated around a Baltimore–Philadelphia axis, but also stretched as far as New York and Richmond. His range of activity, the number of his partners, and the fact that his account books are so well preserved enable this kind of study.

It is possible to track the business relations that Hollingsworth and his partners had through the transactions recorded in his account books.[20] These transactions are a good fit for network analysis since they represent a link between

16 These years were selected for my analysis because they are the ones for which similar documents were available. I offer a full discussion on this issue in the first chapter of my PhD dissertation ("Les ressources économiques du réseau au défi de la mesure: les commerces de Levi Hollingsworth (Philadelphie, fin XVIIIe siècle").

17 For elements on the economic and merchant context in Philadelphia (with mentions of Hollingsworth), see Thomas M. Doerflinger, *A vigorous Spirit of Enterprise: Merchants and Economic Development in Revolutionary Philadelphia* (Chapel Hill: The University of North Carolina Press, 1986).

18 On the flour trade, see Brooke Hunter, "Rage for Grain: Flour Milling in the Mid-Atlantic", Ph.D. thesis, University of Delaware, 2001.

19 Ann Smart Martin, *Buying into the World of Goods: Early Consumers in Backcountry Virginia* (Baltimore: Johns Hopkins University Press, 2010).

20 This work relies on a database drawn from Hollingsworth's Journals (and completed with his Ledgers) for the years 1785, 1786, 1787, 1791 and 1795. The earlier stages of this database were designed during the ANR MARPROF project (directed by Pierre Gervais, Yannick Lemarchand and Dominique Margairaz). Today the database holds 31,912 transactions from the Historical Society of Pennsylvania (HSP), the Hollingsworth family papers (HFP), 2.a. Ledgers: Ledger K (1785–1786, vol. 20), Ledger L (1786–1788, vol. 21), Ledger N (1790–1791, vol. 23), Ledger P (1794–1796, vol. 24); HSP, HFP, 2.c. Daybooks and Journals: [LH? Sales] Journal 1784–1786, vol. 82), Journal K (1784–1786, vol. 85), Journal L (1786–1788, vol. 86), Journal N (1970–1791, vol. 87), Journal P (1794–1796, vol. 89).

two entities (here, accounts). This paper is not the first to build a network analysis on this kind of account books – C. McWatters and Y. Lemarchand, for instance, explored the potentialities of such sources (even if they studied fictional transactions drawn from a bookkeeping manual).[21] Certain individuals had several accounts open at the same time in the account books (this is obvious for Levi Hollingsworth, but was also the case for some of his partners). I aggregate these accounts to track down individuals and firms (I have 2,366 actors from the 3,317 accounts during the 5 years of the study). What is remarkable (and decisive in this work) is that Early Modern account books (in this case double-entry bookkeeping) kept records of transactions between the partners of the merchants who kept them.[22] Indeed, most of the time, merchants bought and sold goods on credit (they did not pay for them immediately). The credit they gained from another merchant could then be traded to other individuals or firms. This is why Hollingsworth's books often recorded transactions between merchant A and firm B. For instance, merchant A used the book credit he got from selling goods to Hollingsworth to purchase merchandise from firm B. In other terms, these books allow us to observe relations in which Hollingsworth was not directly involved (actors were merely using the credit they got from Hollingsworth). The networks produced from these sources are not ego-networks, but they give us a glimpse into the much more complex structures of trade between a central node (Hollingsworth) and his clients, as well as between these clients[23].

From this data, I elaborate five merchant networks, one for each accounting year.[24] I distinguish these years because accounts were opened and then closed each time. This allows us to study comparable networks in which nodes were

21 Cheryl S. McWatters and Yannick Lemarchand, "Merchant networks and accounting discourse: the role of accounting transactions in network relations," *Accounting History Review* 23, no. 1 (2013): 49–83. For an approach that builds on actual transactions, see Pierre Gervais, "Mercantile Credit and Trading Rings in the Eighteenth Century," *Annales. Histoire, Sciences Sociales (English)* 67, no. 4 (2013): 693–730.

22 William T. Baxter, "Observations on money, barter and bookkeeping," *Accounting Historians Journal* 31, no. 1 (2004): 129–39; Robert Bloom and John Solotko, "Barter accounting in the US during the late eighteenth and early nineteenth centuries," *Accounting History* 9, no. 1 (2004): 91–108.

23 As rich as these account books are, they do not allow for the reconstruction of the entire network of trade between the 2,366 actors that have an account opened in them. Indeed, some of these actors could trade directly with each other, independent of Hollingsworth's credit. The question then becomes: is what is observed from these books indicative of the full network? Research on other material, especially correspondence between members of the network and local dynamics of connection, suggest that this is mostly the case. Louis Bissieres, "Les ressources économiques du réseau au défi de la mesure: les commerces de Levi Hollingsworth (Philadelphie, fin XVIIIe siècle)", PhD. Dissertation, Université Paris 1 Panthéon Sorbonne, 2022.

24 The accounting year does not necessarily follow the calendar year. For instance, 1786 starts on the 20th of February for Hollingsworth, and finishes on the 31st of January 1787.

Year	Nodes	Edges	Density	Diameter*	Average path length
1785	911	2,037	0.0049	6	2.2533
1786	761	1,492	0.0052	7	2.2281
1787	744	1,573	0.0057	5	2.2590
1791	516	1,202	0.0090	6	2.2759
1795	864	1,700	0.0046	4	2.2115

* The role of Levi Hollingsworth in this network could induce the idea that the diameter should be 2 (each actor trading with Hollingsworth). Still, in a given year, an actor could use his account opened in one of Hollingsworth's books to trade solely with other partners of the Philadelphian. For instance, the chain of size 5 in the 1787's network goes from a William Hays to Thomas & Samuel Hollingsworth, Levi Hollingsworth, John Strawbridge, Sarah Alexander, and Jeremiah Warder Parker & C°. During this year, William Hays, Sarah Alexander, and Jeremiah Warder Parker & C° do not transact directly with Hollingsworth.

Tab. 1 The merchant networks from Hollingsworth's account books. I consider undirected graphs here. (If not specified otherwise, all following network metrics were obtained from the "igraph" package in R.)

always simultaneously active (since the individuals traded at least once with Hollingsworth or each other). The time scale is thus yearly, and relies on the definition of coherent units (a set of nodes coexisting during identical periods – years, the main temporal metric a merchant would use to measure his activity – to make them comparable). Still, one must note that these networks were active in different contexts: the aftermath of the American war for Independence and the economic crisis it begat in 1785–1786, and the European (and in some ways Atlantic) revolutionary wars in 1795[25]. Table 1 shows some basic metrics on these five networks. Note that even though these scores vary from one year to the next, they retain a similar magnitude. Although different in their shapes, these five merchant networks are nonetheless comparable.

In an economy defined by risk, and in which trade and credit were paramount, merchants found the solution in repeatedly dealing with well-known partners (maintaining these relations would be a means to ensure access to goods of a specific quality or to safe credit).[26] They organized their activity in the networks

25 Stanley L. Engerman and Robert E. Gallman (ed.), *The Cambridge history of the United States, The colonial era* (Cambridge: Cambridge University Press, 1996); Stanley L. Engerman and Robert E. Gallman (ed.), *The Cambridge history of the United States, The Long Nineteenth Century,* (Cambridge: Cambridge University Press, 2000).

26 The literature is very abundant on these issues. See among other Jean-Yves Grenier, *L'économie d'Ancien Régime. Un monde de l'échange et de l'incertitude* (Paris: Albin Michel, 1996); Sheryllynne Haggerty, *'Merely for Money'?: Business Culture in the British Atlantic, 1750–1815* (Liverpool: Liverpool University Press, 2012); Carolyn Downs, "Net-

they elaborated and maintained.[27] This was even more the case within the young United States, where trade was particularly fragile after the War of Independence[28]. In that sense, these collective structures of trade can be considered resources for those who were involved in them. The stability of these resources (i.e., the fact that, over time, the involvement in a specific merchant network remains profitable) is thus a major issue in economic history. Therefore, it is necessary to understand how these merchant networks changed over time (i.e., how stable the resource really was). Using specific metrics and methods, this paper questions this stability of merchant networks using the records of Levi Hollingsworth[29].

The next three sections examine different levels of analysis within Hollingsworth's networks. In section 2, I focus on the nodes that compose these networks and show that there were major evolutions from one year to the next. In section 3, I consider the overall structure (the configuration of relations between nodes) of these networks, concluding that, despite the turnover of members, there was stability (the network kept the same structure over time)[30]. Merchant networks thus changed their composition but not their structure (there is a form of institution-

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works, trust, and risk mitigation during the American Revolutionary War: a case study," *The Economic History review* 70, no. 2 (2017): 509–28.; Carolyn Downs, "Pirates, Death, and Disaster: Maintaining an Atlantic Trade Network in Late Eighteenth-Century England" in *Cosmopolitan Networks in Commerce and Society, 1660– 1914,* ed. Andreas Gestrich and Margrit Schulte Beerbühl (London: German Historical Institute, 2011): 343–76.

27 Francesca Trivellato, *The familiarity of Strangers. The Sepharadic Diaspora, Livorno and Cross-Cultural Trade in the Early Modern World* (New Haven: Yale University Press, 2009); Xabier Lamikiz, *Trade and Trust in the Eighteenth-Century Atlantic World: Spanish Merchants and Their Overseas Networks* (Rochester: Boydell and Brewer, 2010); Mark Casson, "Networks in economic and business history: a theoretical perspective," in *Cosmopolitan Networks in Commerce and Society, 1660– 1914* ed. Andread Gestrich and Margrit Schulte Beerbühl (London: German Historical Institute, 2011): 17–49; Arnaud Bartolomei *et al.,* "L'encastrement des relations entre marchands en France, 1750–1850. Une révolution dans le monde du commerce?", *Annales HSS* 72, no. 2 (2017): 425–60.

28 Anne Bezanson, *Wholesale Prices in Philadelphia, 1784–1861* (Philadelphia, PA: University of Pennsylvania Press, 1936); Thomas M. Doerflinger, *A vigorous Spirit of Enterprise: Merchants and Economic Development in Revolutionary Philadelphia* (Chapel Hill: The University of North Carolina Press, 1986).

29 On comparisons between different graphs (which are not necessarily temporal but could be) in a highly statistical exploration of distance, see Claire Donnat and Susan Holmes, "Tracking network dynamics: A survey using graph distances," *Annals of Applied Statistics* 12, no. 2 (2018): 971–1012. Their main body of illustrative data is drawn from biology and (in their final example) recipes. This allows for comparisons of a much larger of body of networks than the five I have in this study.

30 This is a point that has also been stressed in a study of dynamic networks of phone calls, reaching the conclusion that social configurations sustain major changes in their composition. Jari Saramäki, Elizabeth A. Leicht, Eduardo López, Sam GB Roberts, Felix Reed-Tsochas, and Robin IM Dunbar, "Persistence of social signatures in human communication," *Proceedings of the National Academy of Sciences* 111, no. 3 (2014): 942–947.

alization, as has been stressed by C. Lemercier).[31] In the fourth section, I focus on the edges of these networks, and especially their diversity, using multilayer analyses. I demonstrate that stability within these networks came from the persistence of specific types of transactions for their members. Applying multilayer methods, I also discuss the methods used to visualize temporal layers.

2. Node evolution in a temporal merchant network

I first question the evolution of networks over time by observing their composition. Focusing on the nodes, I show that there was a constant turnover of members within 18th century merchant networks. I then go further by establishing that, among the actors who remained for several periods in Hollingsworth's network, centrality tended to fluctuate. This leads to the conclusion that networks were unstable structures in terms of composition; this could be a form of fragility – would the networks have collapsed if existing links had disappeared?

2.1 The constant turnover of members in a merchant network

The constant turnover of members in a merchant network primarily stems from the fact that most business relations only appeared in one of the five years I studied (Figure 1). Indeed, most of the actors (65%) in Hollingsworth's network only dealt with him during one period (their account was opened then closed during a single interval, and was not reopened afterwards)[32]. At the other end of the spectrum, 60 actors, including the Philadelphia merchant himself, were present throughout the years 1785, 1786, 1787, 1791, 1795. The turnover was frequent, with firms or individuals seizing opportunities to trade with Hollingsworth (or, through his account books, with someone else), then not keeping their relationship with the merchant afterwards. What I call a merchant network – a structure of trade invested and maintained by merchants over time – had many peripheral changes each year. Most links within a merchant network did not last, since those involved in them disappeared.

By comparing their node compositions, I establish how different two successive networks were (Figure 2). One year's network was partly inherited from the previous one, and still affected the next, but the difference was very important

31 Claire Lemercier, "Taking time seriously. How do we deal with change in historical networks?" in *Knoten und Kanten III. Soziale Netzwerkanalyse in Geschichts- und Politikforschung* ed. Markus Gamper, Linda Reschke and Marten Düring (Bielefeld: Transcript Verlag, 2015), 183–211.

32 I do not track the exact dates of the opening and closing of accounts; instead, I assess the existence of an account within a specific period through its presence in the Ledger and its involvement in at least one transaction.

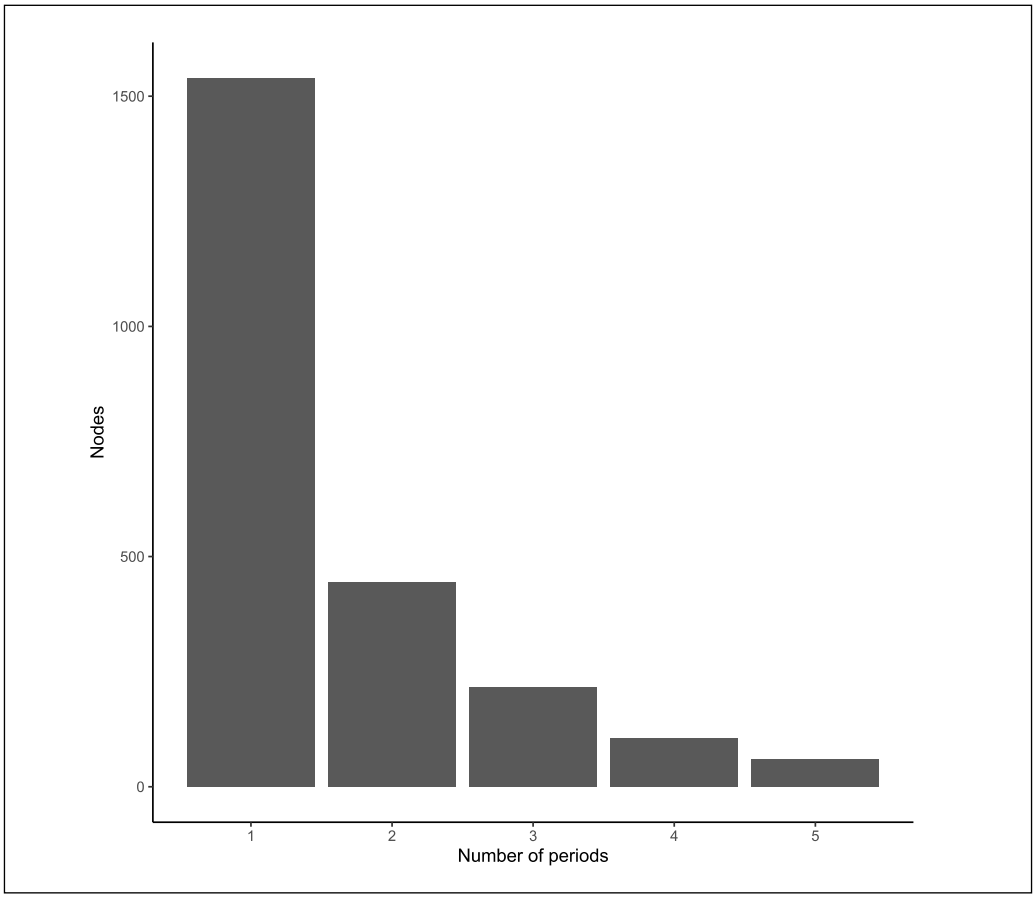

Fig. 1 The number of periods each actor was present in Hollingsworth's networks.

from one to the next. For instance, no more than half of the nodes composing the network of 1787 were already present in 1785 and 1786. There is a continuous effect of time within these networks, since those closest in time had the most similar compositions. This allows us to elaborate on our understanding of merchant networks – they were not monolithic structures (they did not remain the same in their composition), but rather were organized by a small proportion of members who remained involved in them for years. Around these members revolved a series of short-term buyers and sellers who kept goods and credit flowing in a structure they were only temporarily a part of.[33]

33 This is coherent with the distinction P. Gervais makes about insiders and outsiders in merchant networks. Pierre Gervais, "Capitalism and (or) Age of Commerce: the peculiarities of market exchange in the early modern era," *Revue de la Société d'études anglo-américaines des XVIIe et XVIIIe siècles* 77 (2020).

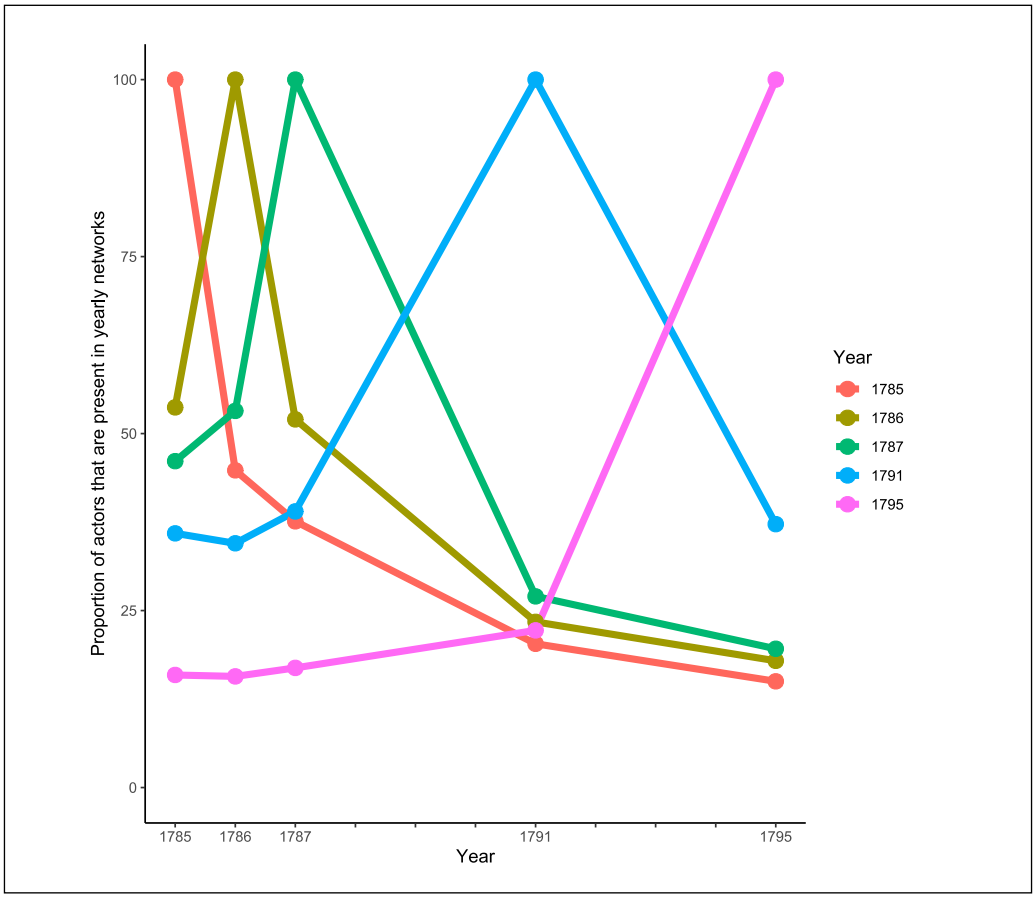

Fig. 2 The turnover of actors in the different merchant networks. Each point represents the part of nodes of the studied network (color) that were present in a yearly network (x axis). 46% of the nodes in the merchant network of 1787 were present in the 1785 network, and 53% of them were in the 1786 network. Only 20% of these nodes were still involved in the 1795 network.

The case of Levi Hollingsworth allows us to assess the effects of time on networks, as well as to establish methods to compare them over time. With two simple metrics (the yearly distribution of the entire set of nodes and the proportion of actors within a yearly network in the others), I reach important conclusions about merchant networks in terms of their instability.[34] This is possible since the

34 This could be complemented with more qualitative work about the elaboration or termination of these business relations, through Hollingsworth's correspondence, for instance. On the elaboration of relations, see Arnaud Bartolomei *et al.*, "Becoming a correspondent. The foundations of new merchant relationships in early modern Europe (1730–1820)" (2018) [working paper].

data allows for a simple and systematic definition of the time scale of the temporal networks (the accounting year).

2.2 Among those who stayed: major evolutions in terms of centrality

The fact that some nodes are present in successive temporal networks is not necessarily sufficient to demonstrate stability. Indeed, this stability can be put in jeopardy if the position of these nodes in the overall structure varies widely. In this subsection, I take the degree centrality of the nodes into consideration to question this stability (similar conclusions could be drawn from the use of other network metrics). I analyse the evolution of degree centrality for each node that appeared in at least two of Hollingsworth's merchant networks. I do this by measuring the variation of degree centrality, answering the question "how much did degree centrality vary from one year to the next?". For each node that is involved in at least two temporal networks, I compute the coeffecient of multiplication (when centrality increases) or the coefficient of division (when it decreases)[35]. For instance, when the centrality of a node goes from 5 to 7, we get a coefficient of 1.4. Likewise, we get a coefficient of 2 when a node's centrality goes from 20 to 10.

I show the distribution of these scores in Figure 3. From 1785 to 1795, there are 1426 cases of actors who remain in the merchant network (and as many potential variations of centrality). There was some sort of variation in 77% of the cases. In other words, only 23% of these variations involved actors who kept the same centrality over two periods. The coefficient doubled for more than 50% of the variations. This implies that it was fairly common for an actor to double the number of his partners from one year to the next, or conversely to lose half of them.

In other words, a member could have many linked partners in the network one year and a few the next, and vice-versa. There are many explanations to such a phenomenon. The cause could be found in the actor's strategies, or those of Hollingsworth. In 1785, Benjamin Randolph, a blacksmith from New Jersey, was one of the most important actors in the network in terms of degree centrality. Through Hollingsworth's account books, he reached 45 other individuals or firms. After a dispute, he decided to stop doing business with the merchant from Philadelphia, only balancing his accounts with him in 1786 (his degree central-

35 For two periods A and B and centrality degrees (deg), when there is an increase, the coefficient of multiplication is $\frac{deg\ B}{deg\ A}$. When there is a decrease, the coefficient of division is $\frac{deg\ A}{deg\ B}$. The idea here is not to differentiate between increases and decreases, but solely to assess variations of centrality. I did not select the coefficient of variation since the interpretation of the coefficient of multiplication or division is more straightforward in this case.

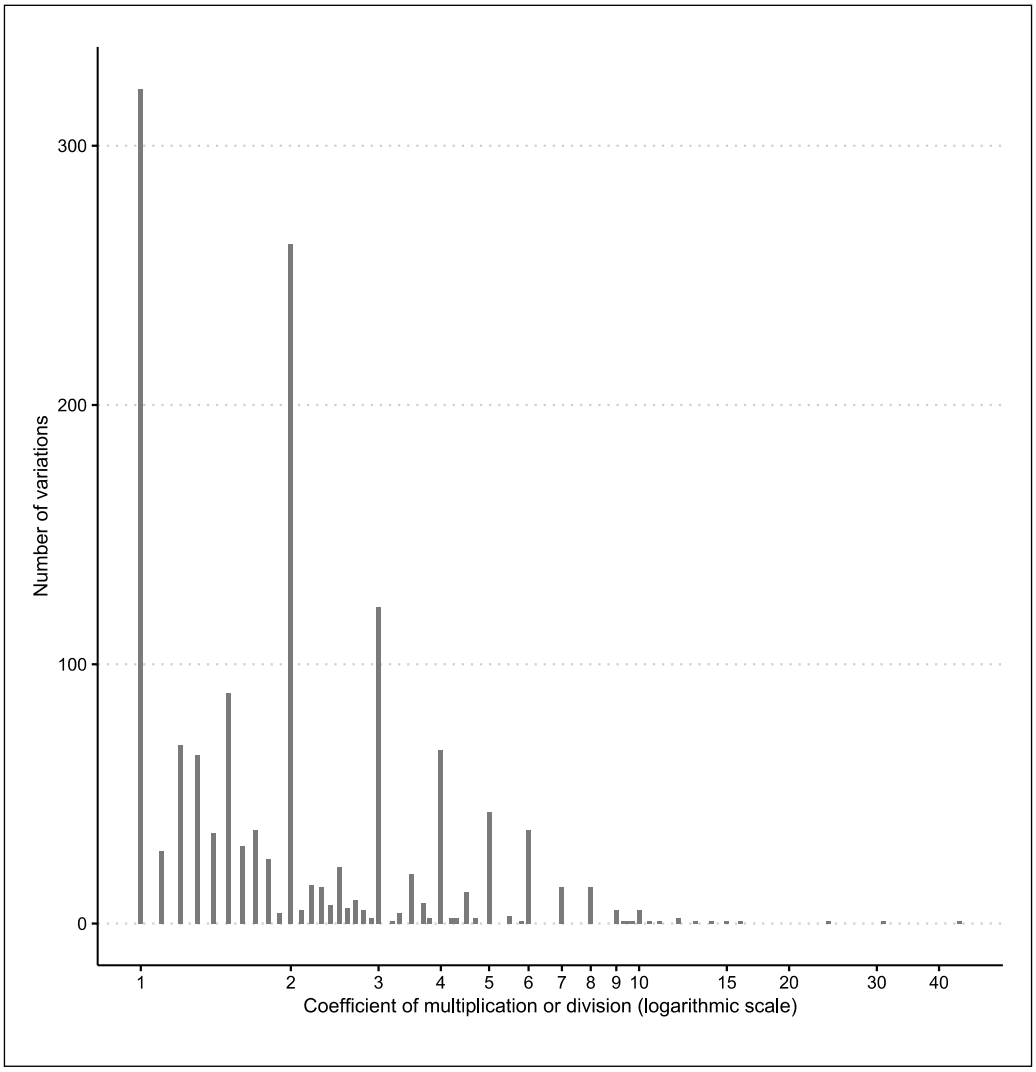

Fig. 3 The distribution of the degree centrality coefficient of multiplication or division between temporal networks. In total, I compute 1426 variations involving 824 nodes. There was no variation of centrality between two years in 322 cases (a coefficient of 1). A node's centrality tripled in 122 cases.

ity was then 1 for this year, and he left the network afterwards).[36] On the other hand, some of the changes in actors' centralities were a direct result of Hollingsworth's strategies. The rise of Solomon Townsend from New York, and the fall of John Jones, a merchant active in the Caribbean, tell this story. The two trajectories follow Hollingsworth's shift in the focus of his business from 1786. Indeed, he progressively gave up on importing goods from the Caribbean (which were in part provided by John Jones) and increased his trade in manufactured goods (Solomon Townsend was an anchor maker). John Jones' degree centrality went from 59 in 1785 to 17 in 1786–1787 and 5 in 1795. Solomon Townsend entered the network in 1786, had accounting links with 19 members, and subsequently 58 in 1791 and 80 in 1795.

These few examples show how unstable the positions in merchant networks could be for those who were involved in them. Focusing on degree centrality allows us to emphasize this conclusion. In these examples, I place the emphasis on nodes with high centrality, but note that the coefficient of variation could be even higher for the less important nodes, since change had a greater effect on them (gaining two new connections for a node that only had two to begin with leads to a coefficient of 2, while the same gain for a node that had 10 only leads to a coefficient of 1.2). Nodes appeared and disappeared in networks, and those that stayed may have seen their position change drastically over time.

Considered outside of a temporal chain, an 18th merchant network appears as an organized structure, revolving around certain key members and allowing an efficient flow of goods and information. In this case, in 1786, these key members were Levi Hollingsworth and his closest partners (his brothers Thomas and Samuel in Baltimore, another brother, Zebulon, in Elkton, Solomon Maxwell in Christiana Bridge, and George Douglass in New York). Taking the temporal continuity of these networks into consideration provides a different impression, however. For instance, George Douglass' time in the network was short: he appeared at the end of 1785, went bankrupt in 1790, and never repaid his debts afterwards.[37] In this sense, observing the turnover of members challenges the sense of stability that could emerge from a focus on one single temporal network.

36 Letter from Benjamin Randolph to Levi Hollingsworth, 23 November 1785. HSP, HFP, 1.a. Correspondence, Incoming, box 29, folder 1.

37 George Douglass, letter to Levi Hollingsworth, 22 October 1785, HSP, HFP, 1.a. Correspondence, Incoming, box 28, folder 8; Levi Hollingsworth letter to Murray & Samson, 18 June 1790, HSP, HFP, 1.b. Correspondence, Outgoing, Letterbook, vol. 2.

3. Stability in the overall structure

The members of merchant networks tended to change, by around half, from one year to another. In this section, I show that, despite major evolutions in the presence of nodes and their positions, there was a form of stability in the structure of these 18th merchant networks. I make this observation by shifting my focus from nodes to general metrics concerning the five temporal networks. In doing so, I establish that even if they changed in terms of composition, they remained organized in similar ways. In particular, these networks were systematically hierarchical (3.1) and segmented (3.2)[38].

3.1 Stability in the network hierarchy

The degree distribution allows us to compare the five temporal merchant networks in terms of hierarchy. Indeed, this is a way to evaluate the number of nodes that were central (high degree) and peripheral (low degree). From Figure 4, I observe that this degree distribution is very stable over time, between 1785 and 1795. Each year, there was a single actor dominating the entire distribution (Levi Hollingsworth, as a result of how the data was sampled), then a small proportion of nodes obtaining high scores (degrees of about 10 or more in this case) and a huge population with low to very low degrees (1 or 2)[39]. The yearly variations are minor. For instance, the important nodes were less numerous in 1791, although this is a consequence of the smaller size of the network that year (516 against 820, on average, in the other years). Even if their members changed from one year to the next, I systematically find hierarchies within these networks.

This stability in the hierarchical dimension of networks is even more remarkable if we focus on the relations between the most central nodes and the others. In this section, I set a threshold of 3% to distinguish between the central nodes and the others (the 3% of the nodes that reach the higher degrees of centrality

38 Other parts of my research focus on deep discussions of segmentation and hierarchy in merchant networks. Specifically, I show that these networks were organized by important merchants controlling local clienteles and the transportation of merchandise. These important merchants (central actors) formed a quasi-clique, within which they were almost connected with each other. These observations come from both the exploration of transactions recorded in Hollingsworth's account books with SNA analysis and more qualitative work on his correspondence. See "Les ressources économiques du réseau au défi de la mesure: les commerces de Levi Hollingsworth (Philadelphie, fin XVIIIe siècle)", PhD. Dissertation, Université Paris 1 Panthéon Sorbonne, 2022. In this paper on dynamic networks, I focus on monitoring the evolution of metrics concerning hierarchy and segmentation, building on this research rather than demonstrating all of it.

39 Besides the centrality of Hollingsworth, which is a direct product of my sample of transactions, we observe other forms of centrality that are independent from the sample: in Hollingsworth's books, some personal accounts detained by specific merchants were paramount in credit circuits.

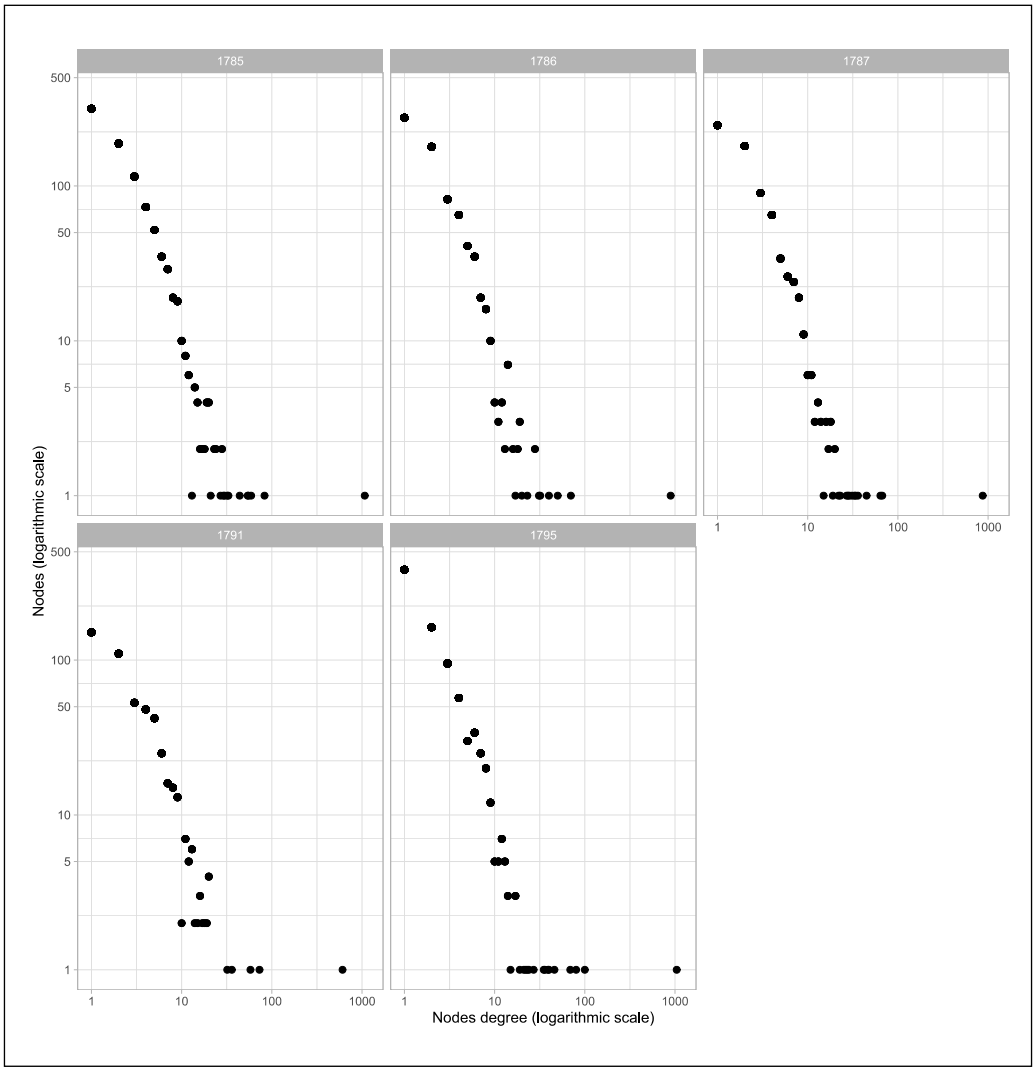

Fig. 4 The degree distribution of the five merchant networks.

are defined as central)[40]. According to the overall number of nodes, there are between 16 and 28 central actors each year. I then define a clientele as the set of non-central nodes attached to a central node. This occurred when a non-cen-

40 After a series of comparisons (with 1, 2, 4, 5 and 10%), it appears that the 3% threshold is the one that best captures the distinction between central and not central nodes in Hollingsworth's network. Beyond 4%, the population of central actors would be too large and lose its internal coherence. Similarly, some actors who appear to play an important role in the commercial structure (as observed, especially, through Hollingsworth's correspondence) would not make the cut with the 1% and 2% thresholds.

tral actor traded with a central one, or traded with one of his clients while not directly trading with any central actor. In this part of the study, I do not consider Levi Hollingsworth's clientele. For the purposes of comparability, I only focus on the other central actors' clienteles.

In Figure 5, I establish the stability of belonging to the clienteles over time. Indeed, whatever the year, the distribution of the number of clienteles that non-central actors were a part of is similar. The most common number of clienteles a non-central actor was a part of is 1, which means that most of them were exclusive clients (they were attached to a single central actor). After that, the belonging within clienteles decreases for those involved in two to ten of them (who had a relation with more than one central actor). Each year, about 15% of the non-central actors that engaged in relations with some of Hollingsworth's partners did not belong to any clientele.

In themselves, these numbers are of interest for the economic historian. They help to establish a form of segmentation of merchant networks that is organized around central actors and their clients, since exclusive clienteles were so numerous. What is remarkable for this work about the evolutions of a merchant network over time is the stability of this distribution. Changes from one year to the next were minor. For instance, the exclusive clienteles systematically represented between 49 and 53% of the whole. For each year, the distribution strictly decreased in those who belonged to 1 to 5 clienteles. One of the minor changes I observe is the fact that the distribution is denser in 1795, with less actors who belonged to more than 4 clienteles than before. This could indicate that Hollingsworth's network became a little bit more segmented at the end of this period.

Central actors did not necessarily remain long at the top of Hollingsworth's network, either because they stopped being central or because they left. When Benjamin Randolph ceased to be central after his dispute with Hollingsworth, 20 of his clients left the network as well. 18 joined other central actors' clienteles and 7 became part of Hollingsworth's exclusive clientele. This shows that clienteles could be, in part, fluid over the years. While some clients remained with Randolph, others stayed in the merchant network, attaching themselves to other central actors. This is consistent with what I exposed in section 2.2: one year's hierarchy did not replicate in the next, but both networks were hierarchical.

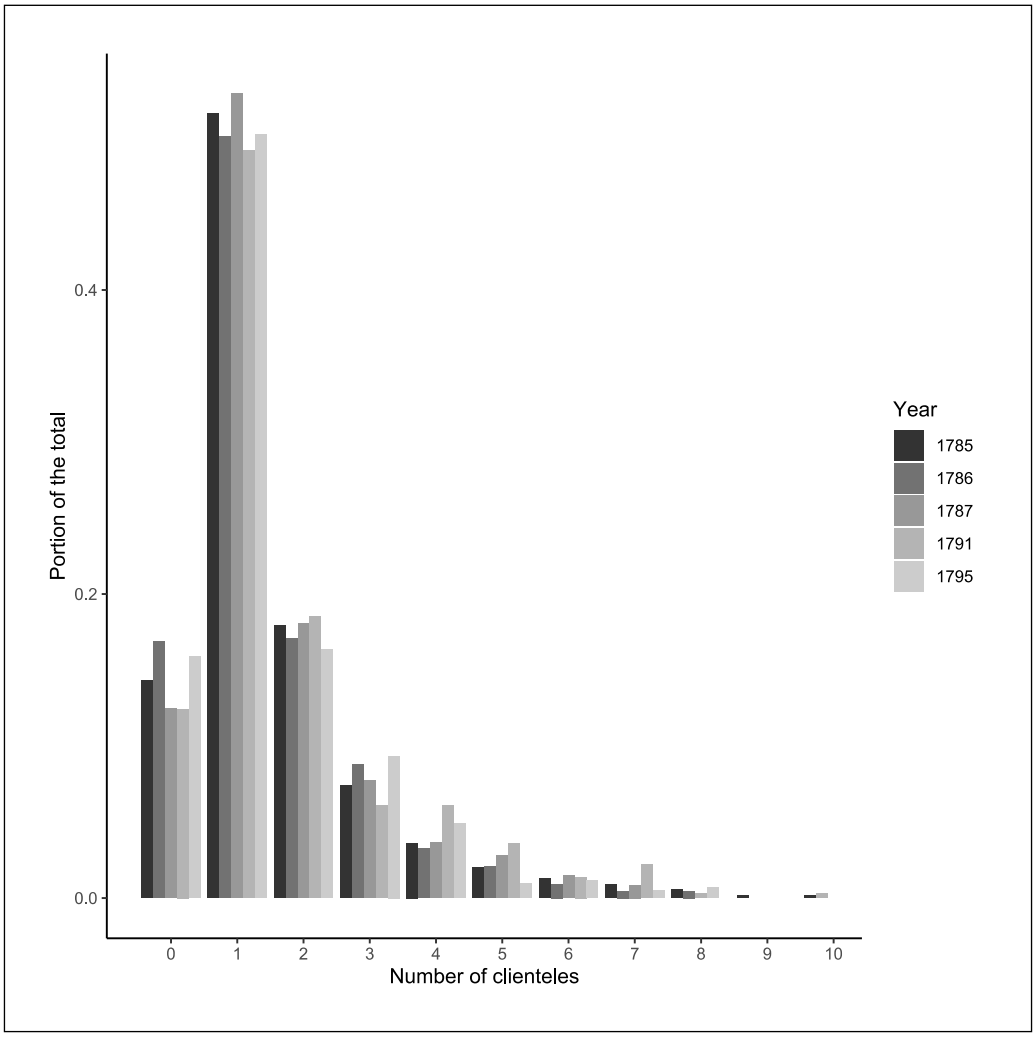

Fig. 5 The number of clienteles network members belonged to. The population considered here is composed of the non-central actors who were not exclusively in relation to Levi Hollingsworth. In other words, it is the population that was using Hollingsworth's account books to exchange book value with some of his partners. Those who did not, the exclusive clients of Hollingsworth, do not appear here. On the x-axis, I represent the number of clienteles that non-central actors were a part of, while the y-axis represents the portion of the clients for each number of clienteles. For instance, 17.5% of the clients belonged to two clienteles in 1785.

3.2 Stability in the closing of clienteles

Our work concerning clienteles has allowed us to show that merchant networks were systems composed of relatively distinct subpopulations, revolving around a single merchant. To ascertain the fact that these networks were indeed segmented into clienteles, I question to what extent the clients of a central actor dealt with each other. To do so, I focus on the sole relations between clients (I exclude relations involving Levi Hollingsworth, and central actors). I elaborate a typology with the three kinds of closure for the relations clients could have: type 1 closure (a relation between two clients of the exact same clientele); type 2 closure (a relation between two clients that partly belonged to the same clientele)[41]; and none (a relation between two clients that belonged to different clienteles).

I show those scores, as well as their evolution over time, in Figure 6. According to the year, the clienteles were, at least partially, closed between 70 and 80%. The type 2 closure was very stable, while type 1 and no closure transactions fluctuated slightly more. Nonetheless, their ranks remained the same over time. The conclusion from this figure is twofold. First, the closure of clienteles was very high. This result contributes to the definition of merchant networks as being segmented (in addition to being hierarchical) structures. Second, there is a very strong degree of stability in the closure of clienteles over time. If there was a decrease in the strongest type of closure after a peak in 1786, this was partly compensated by an increase in the weakest type of closure. Year after year, the distribution of closures was similar. This means that merchant networks' structures overcame the turnover of their members. Even if the clienteles were attached to different central actors, they remained and functioned in similar ways.

There was stability in the closing of clienteles in the successive temporal networks of this study. This result does not take into consideration the identity of the central nodes around which they revolved. Nonetheless, we can shift our focus to the age of specific clienteles. In doing so, I question the effects of time on these clienteles in order to establish whether they strengthened over time (more and more closure) or collapsed (less and less). To do so, I track the different types of closure that characterized the transactions in which the members of clienteles that existed for at least two years were involved in. 22 clienteles fit this definition, and I depict the evolution of their closure in Figure 7. The different figures allow us to distinguish between different paths for the clienteles. Some strengthened, like that of James Douglass, a miller from Delaware, between 1791 and 1795 (with closure type 1 and type 2 combined, which went from 60% to 87%). Others slowly decayed, like that of Thomas and Samuel Hollingsworth. And, finally, others

41 This is the case when, for instance, there is a connection between client X (belonging to clienteles A and B) and client Y (belonging to clienteles A and C).

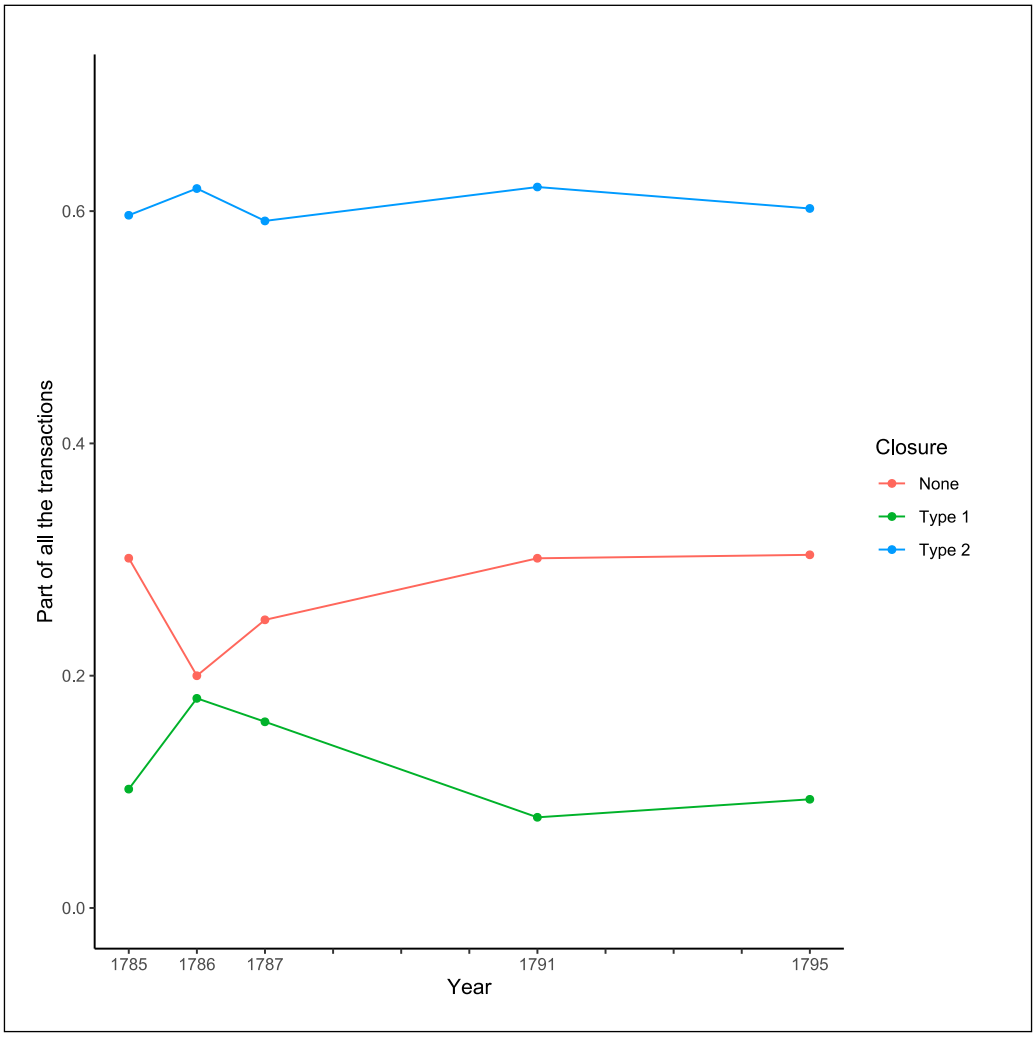

Fig. 6 The closing of clienteles in the Hollingsworth networks. The transactions studied are those that took place between clients.

strengthened before entering a period of decay (the clienteles of Jeremiah Brown, a miller from Pennsylvania, or Snowden & North, merchants from Philadelphia).

This comparison of the different clienteles allows us to note that time affected the clienteles, since they evolved from one year to the next. Still, there is no specific trend that strongly emerges. I generalize the different trends from Figure 7 by focusing on intervals for the clienteles in Figure 8. Indeed, in this part of the study, I do not try to assess if there was an increase in the closing of clienteles between two specific years, as I wish to observe a general trend. For each clientele, I define a series of intervals. Active in 1791 and 1795, William Cooch's clientele only remains for one interval. Active throughout the whole period, between 1785

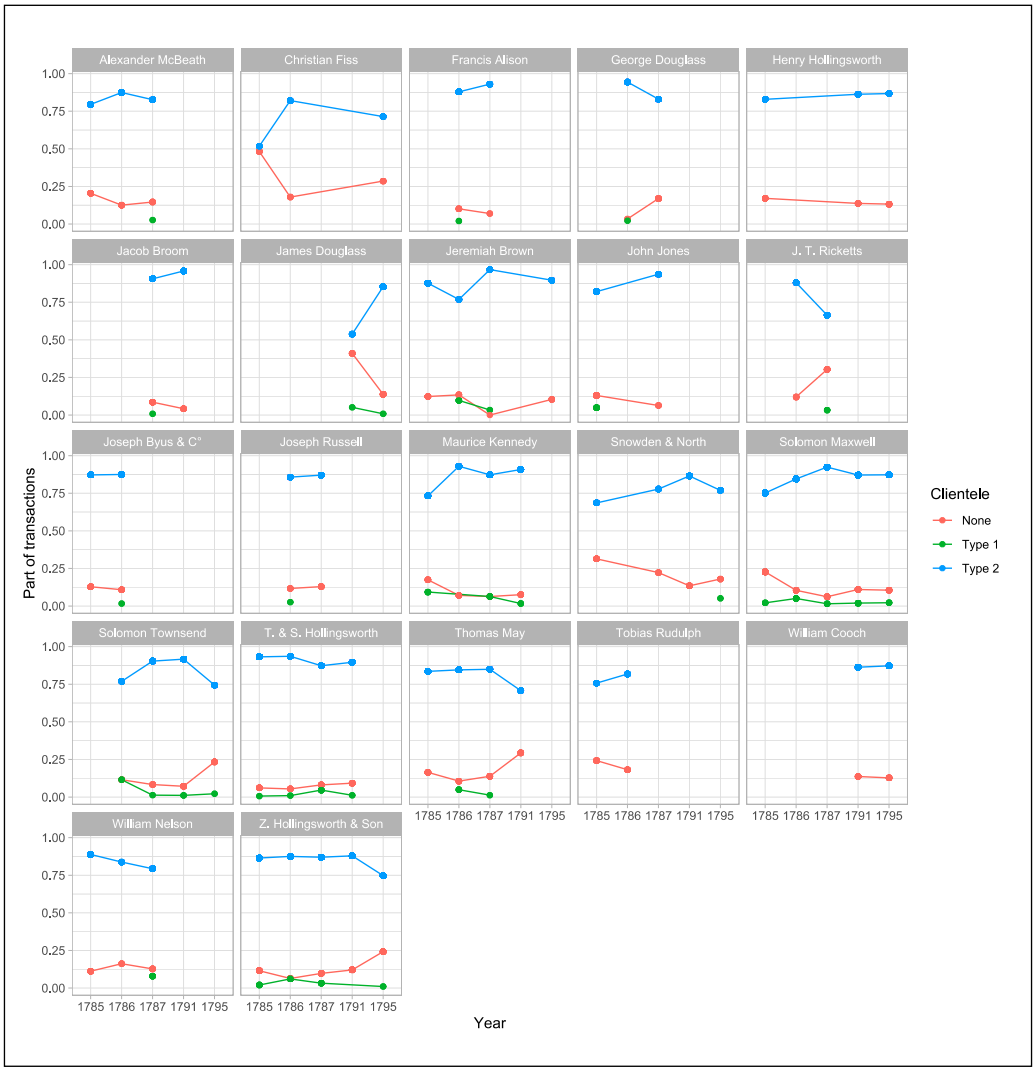

Fig. 7 The clienteles over time. Each figure represents the closing of a specific clientele. Names are those of the central actors these clienteles revolved around. The intervals do not have the same duration (one year for the first two and four years for the last two).

and 1795, Zebulon Hollingsworth & Son's clientele has four intervals. For each interval, I compute the variation of the closing of the clientele (the sum of type 1 and type 2). I normalize these intervals by making them yearly in order to make a comparison possible.[42]

42 Formula: $\frac{closing\ B - closing\ A}{closing\ A \times (year\ B - year\ A)}$

What we see in Figure 8 is that clienteles tended to strengthen during the first two time intervals. Indeed, the average variation of the closing of clienteles is positive. A strong majority of clienteles strengthened during the first interval (even the maximum of the first quartile is positive). The situation is more balanced during the second interval, when a majority of clienteles strengthened, but some started to collapse. The collapse was then general during the third and fourth intervals. This allows us to draw a general narrative for these clienteles, as well as the dynamics of merchant networks. When a merchant became central (whether he was in the network before or not), he did so by establishing a clientele around him, within Hollingsworth's account books. It is likely that this merchant had prior relations with some clients. Hollingsworth's books then became another place for them to trade (hence the high scores of closing). The closing increased during two intervals, probably because these clients with prior relations progressively integrated themselves into Hollingsworth's network. The closing then collapsed when these clients seized the opportunity to trade with the clients of other central actors in the network.

This trend tends to confirm the power of merchant networks in the Early Modern period - they were instruments that enabled the perpetual integration of new members. These new members first integrated within these structures because of their prior connections, and then elaborated new ones. It was also shown that these networks continued despite the departure of some members. Although not every client stayed in the network, many of them were dispatched to other clienteles. Despite the turnover of members, there was stability in the way these networks were organized, – they were always hierarchical and segmented. This organization did not prevent time from affecting the different clienteles; however, the renewal of clienteles allowed merchant networks to remain dynamic, and also balanced sets of old and new clienteles. The organization of these networks did not revolve around specific individuals or firms (I established their turnover in section 2), but rather around individuals that occupied specific positions (the central actors, whoever they were)[43].

43 With the exception of three of them, who were always central to the network and controlled the transportation business with Levi Hollingsworth: Thomas & Samuel Hollingsworth from Baltimore (Maryland), Zebulon Hollingsworth from Elkton (Maryland), and Solomon Maxwell from Christiana Bridge (Delaware).

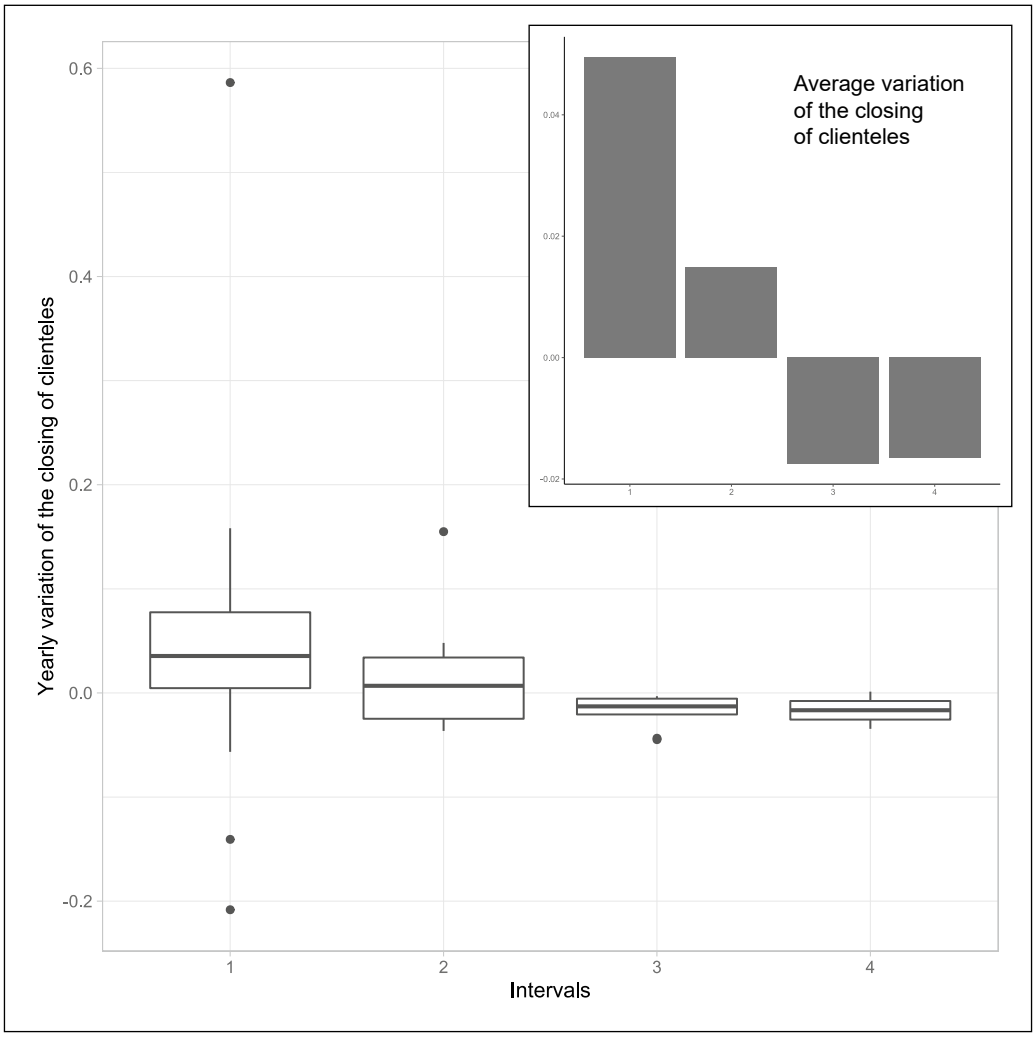

Fig. 8 The yearly variation of the closing of clienteles over time. The x-axis represents the four intervals that can be observed in the data. Inside the boxplot are represented the median of the yearly variation of the closing of clienteles over time. Its minimum represents the first quartile, and its maximum the third. The dots that appear on the graph represent extreme values. The data is composed of 22 first interval, 12 second interval, 8 third interval, and 2 fourth interval. In the top-right corner is a visualization of the average variation of (the mean of) the closing of clienteles.

4. A multi-layered way of considering change

In this fourth section of the study, I focus on the persistence of types of links over time, utilising a multilayer approach.[44] In doing so, I show that the stability of merchant networks mainly stemmed from the fact that their members continued to conduct similar types of trade over time. I develop a double, multi-layered approach to these networks with a static distinction of layers that refer to types of links (i.e., types of transactions) and a dynamic distinction of layers (temporal layers).

I distinguish between the type of transactions to elaborate the different layers.[45] To do so, I rely on a typology that takes into consideration the kinds of assets that were traded in the course of a transaction, as well as the motive underlying this trade.[46] In the case of this study, the individuals or firms that used Hollingsworth's books to trade with each other could only transfer book credit. These transfers of credit had four motives (according to what was stated in the account books): a sale of merchandise; a sale of service; a conversion of paper instruments; or a transfer of what was called the "net proceeds of merchandise". These net proceeds were the result of several sales or purchases of goods, to which Hollingsworth included the costs associated with his fees (in terms of commission or transportation). The use of net proceeds was very common to balance the accounts among (mainly) flour sellers and buyers. From these motives we have four layers: [BC–BC–M] (Book Credit for Book Credit for Merchandise); [BC–BC–S] (Service); [BC–BC–PI] (Paper Instrument); [BC–BC–NPM] (Net Proceeds of Merchandise). Not all motives were indicated in the account books. I also create a fifth layer [BC–BC–NA] for the transfers of book credit with unknown motives (around 12% of the transfers of book credit).

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44 For a theoretical approach of multilayer analysis, see Mark E. Dickison, Matteo Magnani, and Luca Rossi, *Multilayer Social Networks* (Cambridge: Cambridge University Press, 2016).

45 For examples of multilayer analyses in history, see (among others) Charles Van den Heuvel, "Mapping Knowledge Exchange in Early Modern Europe Intellectual and Technological Geographies and Network Representations," *International Journal of Humanities and Arts Computing* 9, no. 1 (2015): 96–114; Ingeborg Van Vugt, "Using multi-layered networks to Disclose books in the Republic of Letters," *Journal of Historical Network Research* 1 (2017): 25–51; Matteo Valleriani *et al.,* "The Emergence of Epistemic Communities in the Sphaera Corpus: Mechanisms of Knowledge Evolution," *Journal of Historical Network Research* 3 (2019): 50–91.

46 This typology was elaborated by Louis Bissieres and Pierre Gervais. It was first presented at the Accounting History Review conference in Edge Hill on the 24th of June of 2021, under the title "Accounts as a multilayered network: a preliminary exploration of the use of network analysis in Early Modern accounting history." A paper entitled "Means of payment in Early Modern double-entry merchant accounting: an exploration using multilayer network analysis" is under review by the Accounting History Review.

With this typology, I define five layers for each year, each composed of the actors involved in a specific kind of transaction. An edge between two nodes indicates that actors traded with each other through the type of transaction associated with the layer. To match this with the dynamic approach, I decompose each of the five static layers into five temporal layers, one for each year of the study.[47] In the end, we have 25 temporal layers. First, I explore what multilayer metrics allow us to say regarding the organization of a merchant network over time. Second, I discuss the challenges of representing different temporal layers.

4.1 Multilayer metrics and the organization of a merchant network over time

In the five merchant networks elaborated from Hollingsworth's account books, transfers of book credit between individuals or firms mainly concerned sales of merchandise (41%) and settlements of the net proceeds of merchandise (35%). Then came indistinct transfers of book credit, followed by those for paper instruments and services. I use multilayer metrics like the Jaccard algorithm to compare the different layers and analyze their importance in the stability of the merchant network (Figure 9).[48] I first observe that interlayer overlapping was never extraordinarily strong. The maximum overlapping we get between two layers is 29%. This means many actors were specialized in one kind of transaction and did not articulate this with other kinds.

In this figure, we see two levels of similarity between layers. First, any single layer shares some similarities with the four other layers of the same year. This is the case in 1787, for instance. In this year, the five layers had some nodes in common (at least 13% for each pair of layers, with the exception of the pair [BC–BC–S]–[BC–BC–NPM] that only shared 8% of actors). This result is expected, since some of Hollingsworth's partners were involved in several kinds of transactions. The second level of similarity between layers is more remarkable. Indeed, we observe that between 1785 and 1787, the strongest proximity for 13 of the 15 layers was with the layer of the same kind, one year before or one year after.[49]

47 On the decomposition of longitudinal networks into time layers, see Dane Taylor, Mason A. Porter and Peter J. Mucha, "Supracentrality Analysis of Temporal Networks with Directed Interlayer Coupling," in *Temporal Network Theory,* ed. Petter Holme and Jari Saramäki (Cham: Springer, 2019), 325–44.

48 For a descriptive approach of multilayer metrics and their application with the "Multinet" package in R, see Matteo Magnani, Luca Rossi and Davide Vega, "Multiplex network analysis with R," *Journal of Statistical Software* 98 (2021): 1–30. The Jaccard distance is also explored in Claire Donnat and Susan Holmes, "Tracking network dynamics: A survey using graph distances," *Annals of Applied Statistics* 12, no. 2 (2018): 971–1012.

49 We see these results in the diagonal starting at [BC–BC–M (A)]–[BC–BC–M (B)]. The two exceptions are the pairs [BC–BC–M (A)]–[BC–BC–NA (A)] and [BC–BC–PI (A)]–[BC–BC–NA (A)].

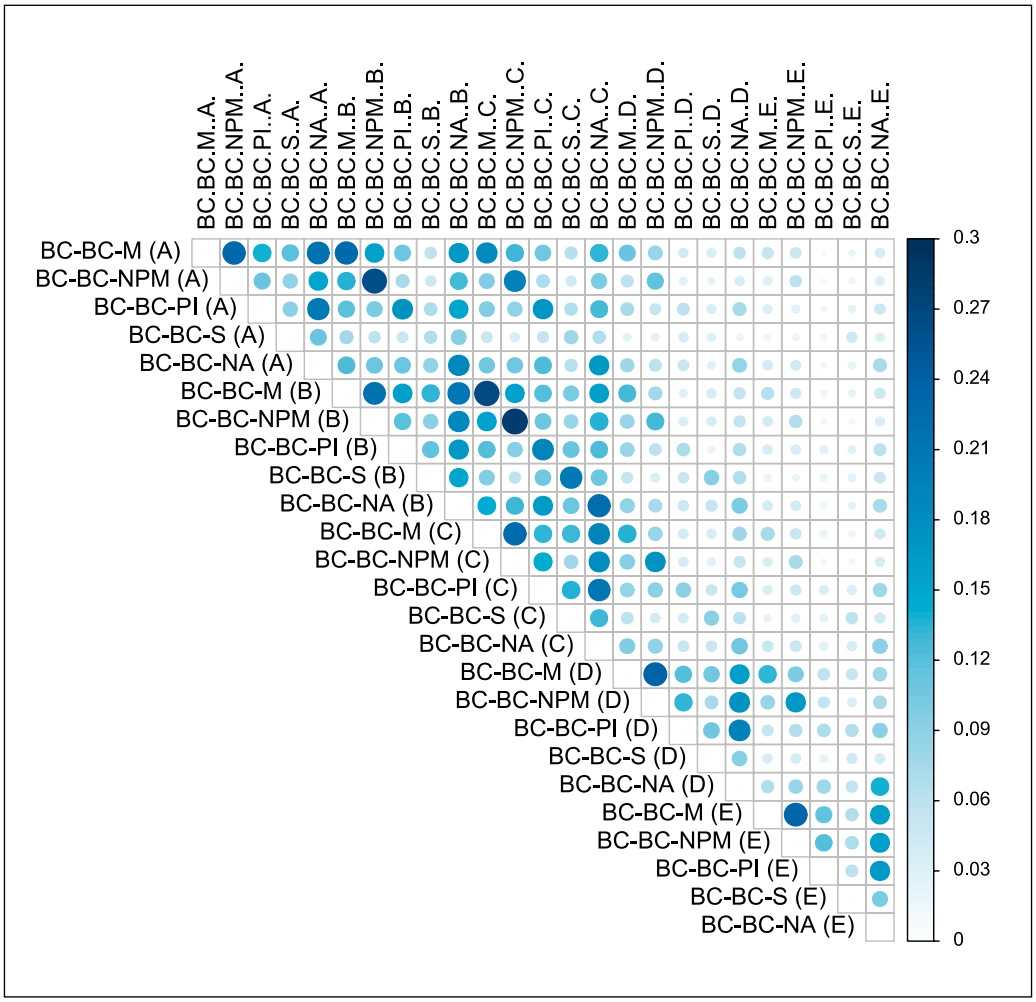

Fig. 9 Overlapping between actors in pairs of layers. In this matrix, I plot the similarity between two temporal layers in their composition. A score of 0 means that two layers did not have any nodes in common, while a score of 1 means the same nodes were present in both layers (the maximum observed here is 0.29). The size and intensity of the color of the points is proportional to the overlapping. I set the diagonal to 0 (otherwise it would only be filled with 1s, which would affect the scale of the graph, and make some comparisons more difficult). For each temporal layer, the letter in parenthesis refers to the period (A to E from 1785 to 1795). (This figure was elaborated in R from metrics produced through the "multinet" package and represented with the "corrplot" package.)

This means that, in most cases, two consecutives temporal layers had stronger similarities than with the other layers of the same year (even if half the networks changed each year in terms of their composition). In other words, the (partial) stability of these networks in their composition came from actors that kept doing the same type of transactions over the years. For them, networks were resources they mobilized in a similar fashion, year after year.

This temporal continuity is also visible in the case of longer intervals. We observe this between 1787 and 1791, and between 1791 and 1795. This also perpetuated during a second time interval, which is what we perceive in the diagonal starting at [BC–BC–M (A)]–[BC–BC–M (C)]. Over long time spans, actors that remained in the merchant networks held similar functions (merchandise buyer or seller, service provider, flour miller settling her sales, among others). Still, the persistence of the same kind of relation (in this case transactions) was not synonymous with the persistence of relations with the same partners. Indeed, we get very low scores in terms of the coverage of edges, which means that the overlapping of edges (the same relation between the same two nodes) between pairs of layers was minimal. The only high scores are between the [BC–BC–NPM] layers over the years. These were a peculiar kind of transaction, since they mostly took the form of transfers of book credit between two accounts held by a same individual or firm. The persistence of these links thus meant only that these individuals kept buying or selling goods that Hollingsworth traded for a commission.

This is consistent with what I stressed at the end of section 3. Networks were fluid structures of trade in which individuals or firms did not necessarily keep doing business with the same partners. What Early Modern merchant networks enabled was the perpetuation of stable forms of trade for them. In networks, they kept finding new partners through the shifting clienteles they were involved in. A multilayer analysis leads us to this conclusion, by distinguishing between different kinds of relations. Time affected the composition of networks, but did not affect much their organization, or the opportunities they offered to their members.

4.2 The challenges of representing different temporal layers

In addition to metrics, I mobilize visualization tools to help stress the changes and continuities in temporal networks. Full merchant networks (tangles of hundreds of nodes and links) are difficult to represent efficiently in their totality;[50] the side-by-side comparison of yearly snapshots would not be satisfactory for the reader. Furthermore, we have seen, throughout the different stages of this work, that conclusions about change in networks can only be drawn when specific questions were asked. Viewing five full graphs is not enough, but focusing on specific

50 See, for instance, Pierre Gervais, "Mercantile Credit and Trading Rings in the Eighteenth Century," *Annales. Histoire, Sciences Sociales (English)* 67, no. 4 (2013): 693–730.

Fig. 10 Five temporal layers for transfers of book credit for paper instruments. I represent (with "igraph" and "ggraph" packages in R) the five temporal layers of Book Credit for Book Credit for Paper Instruments kind of transaction. I do not set the position of nodes, since many of them appear and disappear from one year to the next. Node size refers to the degree centrality; nodes with degrees superior or equal to 10 are labeled (with the exception of Zebulon Hollingsworth & Son's node in 1786, which is labeled despite a degree centrality of 6, for the sake of the example).

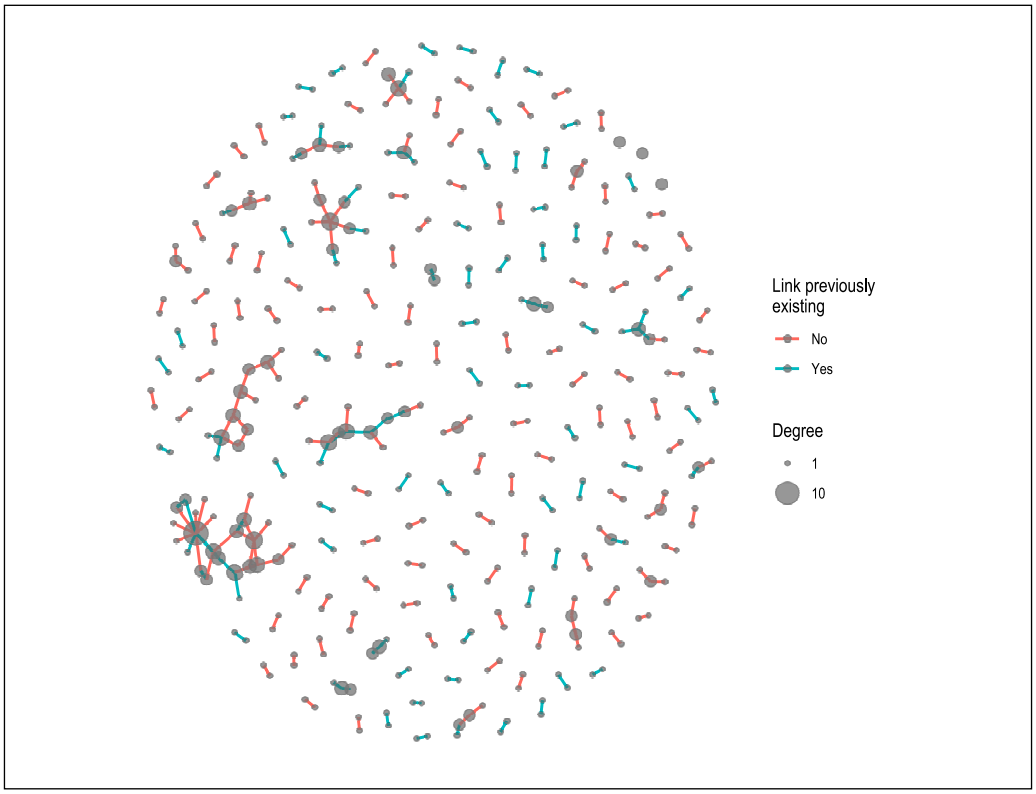

Fig. 11 The persistence of links in the [BC–BC–NPM] layer between 1785 and 1786. The same visual principles as in Figure 10 are used, but labels do not appear. The nodes are in this case accounts. Many of the pairs linked by a single edge are two accounts shared by a same individual or firm.

layers of these networks could be a solution. Indeed, there is a rich literature on the topic of multilayer visualization.[51]

In Figure 10, I take the example of the five temporal layers of transfers of book credit for paper instruments. With a specific kind of transaction like this, we get a sense of comparability in the five graphs, which permits three conclusions. First, these temporal layers appear to have similar organizations, with a large component and a series of peripheral ones. Second, there was growth and decrease for the layer from one year to another. The layers from 1786 and especially, 1791 were smaller and less dense than the other. Third, visualization helps us emphasize certain specific nodes, like Zebulon Hollingsworth & Son in this case. It appears that Levi's brother was key in the trade of paper instruments between his part-

51 Fintan Mcgee *et al.*, "The State of the Art in Multilayer Network Visualization," *Computer Graphics Forum, Wiley* 38, no. 6 (2019): 125–149.

ners. He was systematically one of the two most central nodes in these layers. With the exception of 1786, he was involved in the largest component of the layers. From Figure 9, we know that the transfers of book credit for paper instruments was a type of layer that was not characterised by a particularly strong persistence of nodes, compared to the other layers. Nonetheless, multilayer temporal visualization allows us to see some continuity in the organization of these layers, especially through the stable importance of the key broker of paper instruments, the house of Zebulon Hollingsworth & Son.

A visualization of temporal layers also has avalue in observing the growth of certain components in merchant networks. Indeed, it allows us to picture edges (relations) that have different ages. The multilayer approach contributes to the simplicity of the graph, since all relations are the same type. In Figure 11, I show that the layer of transfers of book credit for net proceeds of merchandise in 1786 was partly inherited from the previous year – 40% of the edges in the 1786 already existed in 1785. What the visualizations add to this number is the opportunity to assess which links persisted, and what this persistence did to the network structure as a whole.

This representation allows us to observe an example of growth in merchant networks, which we find in the largest component, at the bottom-left side of the graph. Indeed, the four nodes at its centre were already connected in 1785 (with three peripheral nodes as well, for a component of size 7). New links emerged from these in 1786, leading to a component of 24 nodes. At the same time, we notice that components were not necessarily inherited from the previous year, as shown by the case of that in the bottom-right of the graph. Besides two peripheral edges, none of these existed before 1786.

Through a multilayer temporal analysis, I have explored forms of continuity in merchant networks. I have established that this continuity mainly resulted from the persistent involvement of certain actors in specific types of transactions. The visualization of these temporal layers, whether in comparing them or in picturing dynamic processes, allows us to characterize this persistence. Layers maintained a similar organization over time, even if they changed in terms of their composition. The observation of edges also led to a better understanding of the dynamics of these layers, especially regarding the growth of some of their components. The visualization thus complements some of the metrics I previously exposed.

5. Conclusion

This paper had a double aim: to show that taking time seriously in an empirical approach of historical networks was possible, and to gain a better understanding of the dynamics of Early Modern merchant networks. From a methodologi-

cal standpoint, I presented several metrics that could be used to characterize the change affecting nodes in a network, in terms of presence and centrality. I also developed methods to assess the stability of the overall structure of temporal networks and, through a multilayer analysis, determined that the type of edges that nodes were involved in mattered in terms of their trajectory inside the network. Multilayer analysis is an efficient tool to approach dynamic networks, as long as temporal layers can be defined. It may be unconventional to approach the edges last, but this work tends to show that it is necessary to gain a good understanding of the overall network structure and thus efficiently observe them. This work has also shown that it is possible to study a form of stability of networks over time, even though there were so few specific connections between pairs of nodes. There can be stability in networks, despite the almost perpetual disappearance of edges and nodes.

Transposed to Early Modern merchant networks, this conclusion is surprising. While some relations between a merchant and his partners persisted, many did not. Still, the merchants kept building new relations, and so kept doing business within these structures of trade – (the networks) they were involved in. Account books recorded these recompositions of relations. Despite a frequent turnover of members, these networks maintained their overall structure. This means that the stability that merchants found in networks was not necessarily in trading with the same people, but in doing business with their partner's partners. In the case of this study, the merchants who dealt with Hollingsworth over the years kept doing transactions with renewed members of the network. They brought part of their clienteles with them into the network and then consolidated them, before seeing them merge with those of others.

Multilayer analyses are helpful in order to understand that members who remained in the network mainly continued to do the same kind of business from one year to the next. As a broker of book credit, Levi Hollingsworth allowed his partners to trade together in an economy in which species were scarce[52]. He benefited greatly from this situation, gaining access to new buyers and suppliers through his partners' clienteles. Merchant networks were a resource (as institutions of trade) for all of them[53]. They were also a stable resource, despite having a very unstable composition. What was key was the opportunity to keep doing steady business, and to find new partners to do it with.

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52 Terry Bouton, "Moneyless in Pennsylvania: Privatization and the Depression of the 1780's." in Cathy D. Matson (ed.), *The Economy of Early America: Historical Perspectives & New Directions,* (Harrisburg, PA: Pennsylvania State University Press, 2006), 218–235.

53 Louis Bissieres, "Les ressources économiques du réseau au défi de la mesure: les commerces de Levi Hollingsworth (Philadelphie, fin XVIIIe siècle)", PhD. Dissertation, Université Paris 1 Panthéon Sorbonne, 2022.

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