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RESEARCH ARTICLE

THE DEMAND EFFECTS OF PRODUCT RECOMMENDATION NETWORKS: AN EMPIRICAL ANALYSIS OF NETWORK DIVERSITY AND STABILITY

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Appendix

Product Network Structures and Metrics

Figures A1 and A2 present the co-view and co-purchase networks at the midpoint (September 1, 2012) of the sample period. Tables A1 and A2 summarize the corresponding network metrics.

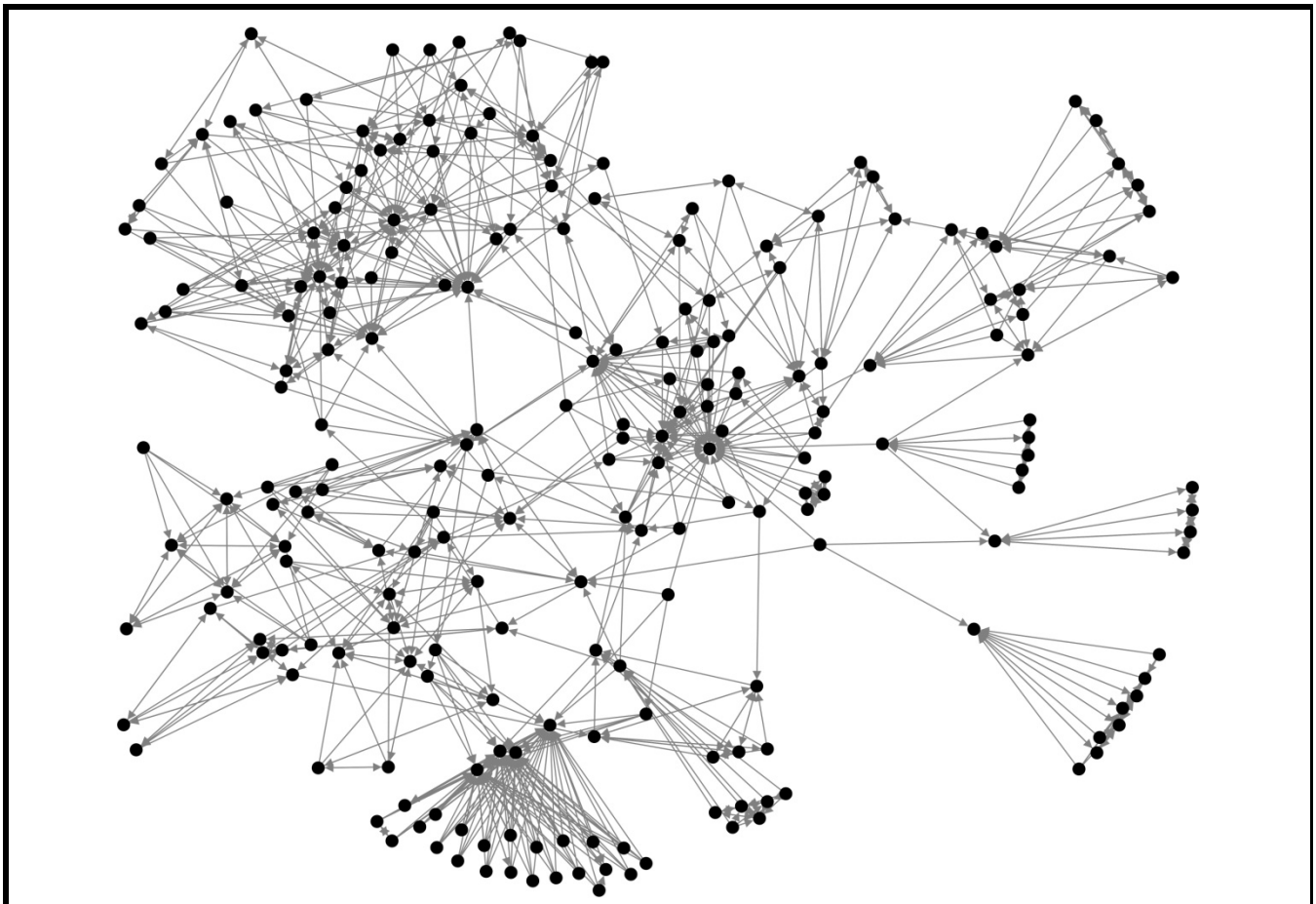

Figure A1. Co-View Network Structure

Table A1. Co-View Network Metrics

Metric	Mean	Std. Dev.	Min	Max
In-degree centrality	4.000	5.597	0.000	37.000
Out-degree centrality	4.000	0.000	4.000	4.000
Betweenness centrality	565.644	1,549.084	0.000	17,502.777
Closeness centrality	0.009	0.029	0.001	0.143
Eigenvector centrality	0.004	0.012	0.000	0.074
PageRank	1.000	0.634	0.587	5.365
Clustering coefficient	0.452	0.300	0.000	1.000

Notes: Number of nodes = 225; Number of edges = 900; Graph density = 0.018.

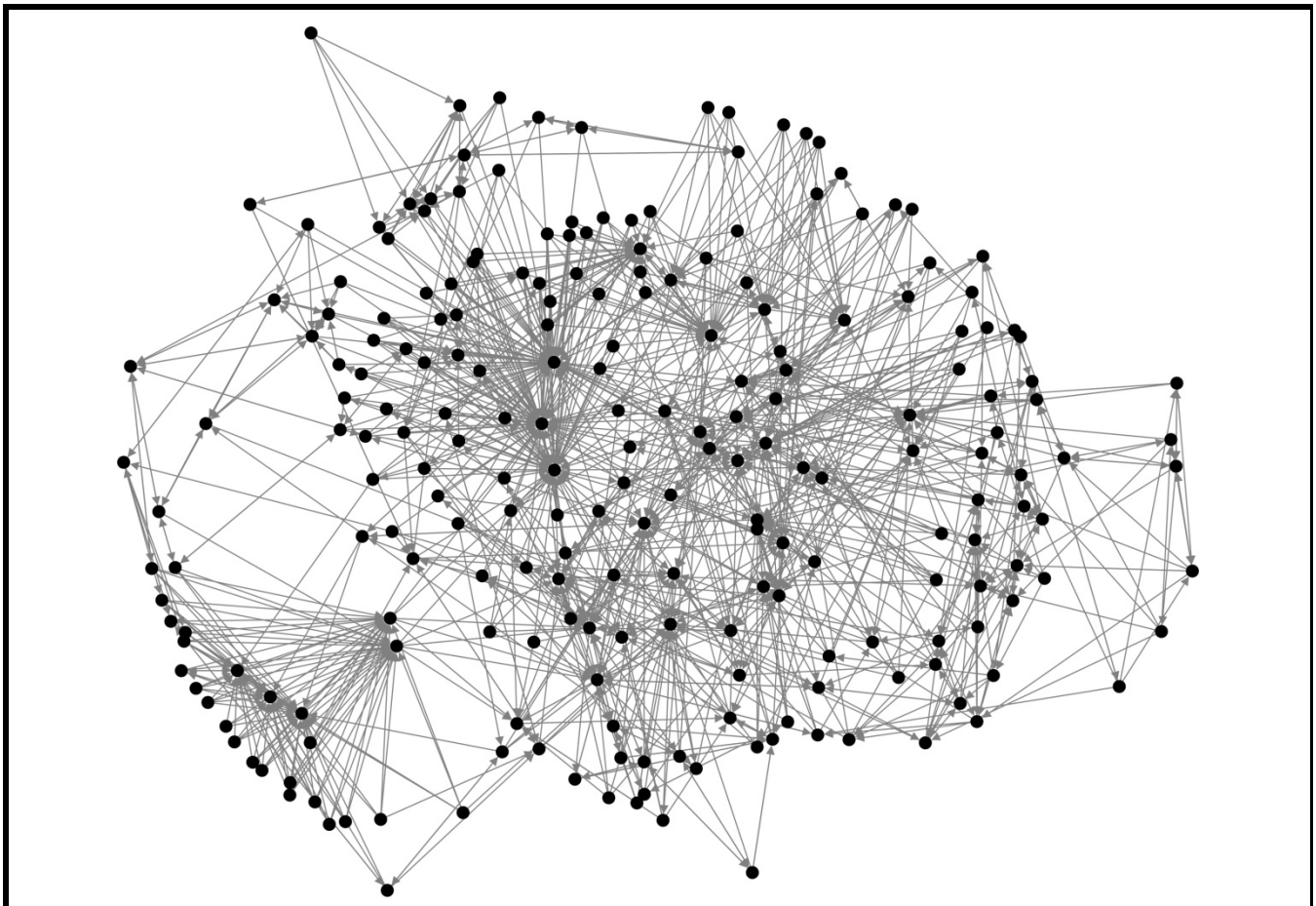

Figure A2. Co-Purchase Network Structure

Table A2. Co-Purchase Network Metrics

Metric	Mean	Std. Dev.	Min	Max
In-degree centrality	4.942	9.298	0.000	72.000
Out-degree centrality	4.942	0.269	3.000	5.000
Betweenness centrality	386.347	1,098.046	0.000	9,634.566
Closeness centrality	0.002	0.000	0.001	0.002
Eigenvector centrality	0.004	0.004	0.000	0.034
PageRank	1.000	0.879	0.509	7.415
Clustering coefficient	0.174	0.156	0.000	0.650

Notes: Number of nodes = 225; Number of edges = 1,125; Graph density = 0.022.

Descriptive Statistics (Product Category)

Table A3 presents the descriptive statistics of product categories included in our main sample of digital cameras.

Table A3. Descriptive Statistics (Product Category)

Variable	Mean	Std. Dev.	Min	Max
QUAN1 (Sales quantity: accessory)	33.863	112.720	0.000	2,200.000
QUAN2 (Sales quantity: battery)	3.349	5.898	0.000	36.000
QUAN3 (Sales quantity: compact camera)	2.313	4.967	0.000	50.000
QUAN4 (Sales quantity: flash)	0.056	0.275	0.000	2.000
QUAN5 (Sales quantity: lens)	1.019	2.105	0.000	26.000
QUAN6 (Sales quantity: SLR camera)	4.514	6.857	0.000	73.000
LP1 (List price: accessory)	302.980	355.428	1.000	2,550.000
LP2 (List price: battery)	282.417	139.319	48.000	978.000
LP3 (List price: compact camera)	1,319.572	389.374	376.000	2,770.000
LP4 (List price: flash)	2,572.396	386.164	848.000	3,578.000
LP5 (List price: lens)	6,551.921	3,943.045	499.000	13,024.500
LP6 (List price: SLR camera)	6,396.445	4,291.084	2,546.000	15,087.420
PV1 (Review volume: accessory)	18.502	19.071	0.000	102.500
PV2 (Review volume: battery)	79.662	157.054	0.000	639.500
PV3 (Review volume: compact camera)	30.967	54.525	0.000	275.500
PV4 (Review volume: flash)	1.000	0.989	0.000	6.000
PV5 (Review volume: lens)	7.964	18.202	0.000	147.000
PV6 (Review volume: SLR camera)	179.917	179.716	0.000	634.000
PR1 (Review rating: accessory)	3.463	1.770	0.000	5.000
PR2 (Review rating: battery)	3.800	1.145	0.000	5.000
PR3 (Review rating: compact camera)	3.323	1.380	0.000	5.000
PR4 (Review rating: flash)	1.991	1.756	0.000	5.000
PR5 (Review rating: lens)	2.691	1.725	0.000	5.000
PR6 (Review rating: SLR camera)	3.710	1.480	0.000	5.000
PS1 (Past monthly sales quantity: accessory)	19.956	22.639	0.000	100.000
PS2 (Past monthly sales quantity: battery)	32.896	60.624	0.000	311.933
PS3 (Past monthly sales quantity: compact camera)	12.070	20.042	0.000	92.833
PS4 (Past monthly sales quantity: flash)	0.426	0.856	0.000	7.500
PS5 (Past monthly sales quantity: lens)	3.206	5.577	0.000	35.000
PS6 (Past monthly sales quantity: SLR camera)	63.832	72.856	0.000	314.000
IN1 (Inventory: accessory)	2,867.024	4,661.136	8.500	38,857.000
IN2 (Inventory: battery)	259.014	269.346	1.500	1,290.500
IN3 (Inventory: compact camera)	523.199	504.865	7.000	3,511.500
IN4 (Inventory: flash)	209.769	306.949	4.500	2,994.500
IN5 (Inventory: lens)	66.008	97.170	2.500	612.500
IN6 (Inventory: SLR camera)	490.337	583.760	1.000	7,053.500
BM1 (Number of bookmarks: accessory)	23.005	32.749	0.000	185.213
BM2 (Number of bookmarks: battery)	152.111	286.563	0.000	1,248.500
BM3 (Number of bookmarks: compact camera)	118.589	158.925	1.000	737.500
BM4 (Number of bookmarks: flash)	15.569	8.891	4.000	76.500
BM5 (Number of bookmarks: lens)	66.406	93.617	1.000	514.000
BM6 (Number of bookmarks: SLR camera)	4,105.217	3,733.216	0.000	12,114.000

Note: Number of observations = 533.

Model Estimation Results (Product Category)

Table A4 presents the product category level model estimation results. The Hausman test results suggest that a random effects model should be chosen over a fixed effects model for all the six categories.

Table A4. Model Estimation Results (Product Category)

Variable	(1) Accessory		(2) Battery		(3) Compact camera		(4) Flash		(5) Lens		(6) SLR camera	
	Fixed Effects	Random Effects	Fixed Effects	Random Effects	Fixed Effects	Random Effects	Fixed Effects	Random Effects	Fixed Effects	Random Effects	Fixed Effects	Random Effects
LP1 (List price: accessory)	-0.249 (0.164)	-0.420*** (0.155)	-0.137 (0.089)	-0.294** (0.135)	-0.144* (0.055)	-0.180*** (0.028)	0.087** (0.023)	0.142*** (0.028)	0.227** (0.066)	0.234*** (0.053)	0.186* (0.076)	0.021 (0.083)
LP2 (List price: battery)	0.728** (0.201)	0.867*** (0.269)	-0.766 (0.373)	-0.577* (0.334)	0.115 (0.051)	0.112* (0.062)	0.085 (0.057)	0.018 (0.043)	0.568*** (0.045)	0.534*** (0.041)	0.377 (0.294)	0.429* (0.259)
LP3 (List price: compact camera)	-0.166 (0.203)	-0.159 (0.241)	-0.136 (0.059)	-0.139*** (0.053)	-0.356** (0.105)	-0.355*** (0.102)	0.036 (0.015)	0.038** (0.017)	-0.036 (0.023)	-0.033 (0.023)	-0.037 (0.028)	-0.026 (0.018)
LP4 (List price: flash)	-0.060 (0.159)	-0.310* (0.178)	-0.026 (0.090)	-0.126** (0.059)	-0.214*** (0.025)	-0.132*** (0.036)	-0.272* (0.105)	-0.273*** (0.030)	0.005 (0.070)	-0.006 (0.058)	0.001 (0.092)	-0.056 (0.048)
LP5 (List price: lens)	0.028** (0.007)	0.028*** (0.004)	-0.002 (0.007)	-0.002 (0.008)	0.005** (0.001)	0.006** (0.003)	-0.000 (0.001)	-0.001 (0.001)	-0.127*** (0.009)	-0.127*** (0.009)	-0.001 (0.012)	0.002 (0.012)
LP6 (List price: SLR camera)	0.029 (0.040)	0.046 (0.051)	0.021* (0.009)	0.037 (0.027)	0.001 (0.026)	-0.013 (0.023)	-0.000 (0.005)	-0.003 (0.003)	0.019 (0.030)	0.015 (0.024)	-0.124** (0.038)	-0.138*** (0.042)
Control variables	-included-		-included-		-included-		-included-		-included-		-included-	
Number of observations	533		533		533		533		533		533	
Hausman test	χ^2 = 17.66, p = 1.00		χ^2 = 29.34, p = 1.00		χ^2 = 7.56, p = 1.00		χ^2 = 73.57, p = 1.00		χ^2 = 2.13, p = 1.00		χ^2 = 17.52, p = 1.00	
R^2	0.7670	0.9123	0.5415	0.8889	0.7822	0.8674	0.3349	0.7551	0.8160	0.8663	0.8610	0.9035

Notes: Standard errors in parentheses. *p < 0.1, **p < 0.05, ***p < 0.01. All the six price variables were divided by 1,000 before estimations. For brevity, only price estimates are reported.

Granger Causality Tests

Table A5 presents the results of Granger causality tests based on different time lag levels from 1 day to 7 days.

Table A5. Granger Causality Test

No. of lags	*ID_CV*		*ID_CP*		*OD_CV*		*OD_CP*		*IS_CV*		*IS_CP*		*OS_CV*		*OS_CP*	
	χ^2	*p*	χ^2	*p*	χ^2	*p*	χ^2	*p*	χ^2	*p*	χ^2	*p*	χ^2	*p*	χ^2	*p*
1	0.638	0.425	0.024	0.876	2.585	0.108	0.511	0.475	2.359	0.125	2.731	0.098	2.404	0.121	3.054	0.081
2	2.902	0.234	0.653	0.722	3.159	0.206	0.570	0.752	3.130	0.209	3.814	0.148	3.335	0.189	4.997	0.082
3	1.934	0.586	0.977	0.807	1.658	0.646	1.392	0.707	4.759	0.190	4.980	0.173	4.240	0.237	6.169	0.104
4	2.253	0.689	2.715	0.607	3.913	0.418	4.265	0.371	8.189	0.085	7.910	0.095	4.472	0.346	6.735	0.151
5	3.626	0.604	4.631	0.463	4.154	0.528	4.011	0.548	7.954	0.159	8.630	0.125	4.349	0.500	7.496	0.186
6	3.623	0.728	5.855	0.440	3.511	0.742	4.183	0.652	7.534	0.274	8.785	0.186	5.460	0.486	8.700	0.191
7	3.700	0.814	7.405	0.388	3.633	0.821	4.300	0.745	8.251	0.311	10.569	0.159	5.640	0.582	9.051	0.249

Shuffle Tests

There are three major steps for the shuffle test. First, we compute all the diversity and stability variables based on our main model and operationalization. Thus, we will have a set of diversity and stability values for each product in each time period before shuffling. Second, for each focal product, we then randomly shuffle those diversity and stability values over all its time periods while keeping all the other measures (e.g., degree centrality, price, etc.) unchanged. Thus, we will have a randomized set of diversity and stability values for each product in each time period after shuffling. We note that this step is equivalent to randomly shuffling different sets of connected links (i.e., with no change in any single link within a set) for a focal product over various time periods, and keeping the control variables unchanged in a time period. Finally, we estimate Equation (1) separately based on the above two sets of before-shuffling and after-shuffling measures, and perform the Chow test to test for structural differences across these two sets of model parameters before and after shuffling.

Table A6 presents the results of a set of shuffle tests based on different seed values of 1, 2, 3, 4, and 5 used to generate a sequence of random numbers for shuffling. The five sets of Chow test results all indicate that the estimated parameters before and after shuffling are significantly different, thus providing some evidence for the causal effect of network diversity and stability on product demand.

Table A6. Shuffle Test

Variable	(1) Before shuffling (Preferred)	(2) After shuffling (Seed = 1)	(3) After shuffling (Seed = 2)	(4) After shuffling (Seed = 3)	(5) After shuffling (Seed = 4)	(6) After shuffling (Seed = 5)
ID_CV (Incoming, diversity, co-view)	-0.001 (0.003)	0.002 (0.002)	0.007*** (0.002)	0.004 (0.002)	0.007*** (0.002)	0.002 (0.002)
ID_CP (Incoming, diversity, co-purchase)	0.010*** (0.001)	0.008*** (0.001)	0.010*** (0.001)	0.006*** (0.001)	0.009*** (0.001)	0.006*** (0.001)
OD_CV (Outgoing, diversity, co-view)	-0.003 (0.004)	-0.007*** (0.003)	-0.012*** (0.003)	-0.010*** (0.003)	-0.009*** (0.003)	-0.007*** (0.003)
OD_CP (Outgoing, diversity, co-purchase)	-0.008*** (0.002)	-0.003** (0.001)	-0.003*** (0.001)	-0.002** (0.001)	-0.002** (0.001)	-0.001 (0.001)
IS_CV (Incoming, stability, co-view)	0.005 (0.003)	0.006* (0.003)	0.008** (0.003)	0.004 (0.003)	0.005 (0.003)	0.006* (0.003)
IS_CP (Incoming, stability, co-purchase)	-0.000 (0.003)	0.004 (0.003)	0.009*** (0.003)	0.004 (0.003)	0.005* (0.003)	0.007** (0.003)
OS_CV (Outgoing, stability, co-view)	0.006 (0.004)	-0.003 (0.004)	-0.001 (0.004)	-0.006 (0.004)	-0.000 (0.004)	-0.004 (0.004)
OS_CP (Outgoing, stability, co-purchase)	-0.017*** (0.003)	-0.003 (0.003)	-0.007** (0.003)	-0.001 (0.003)	-0.004 (0.003)	-0.003 (0.003)
Constant	0.323*** (0.046)	0.324*** (0.046)	0.322*** (0.046)	0.327*** (0.046)	0.322*** (0.046)	0.323*** (0.046)
Control variables	-included-	-included-	-included-	-included-	-included-	-included-
Number of observations	41,379	41,379	41,379	41,379	41,379	41,379
Chow test		F = 1.99, p = 0.04	F = 2.89, p = 0.00	F = 3.09, p = 0.00	F = 2.64, p = 0.01	F = 2.67, p = 0.01
R^2	0.4934	0.4931	0.4939	0.4930	0.4935	0.4929

Notes: Standard errors in parentheses. *p < 0.1, **p < 0.05, ***p < 0.01.

Descriptive Statistics (Personal Computers, Mobile Phones, Cosmetic Products)

Tables A7 to A9 present the major descriptive statistics for product categories of personal computers, mobile phones and cosmetic products, respectively.

Table A7. Descriptive Statistics (Personal Computers)

Variable	Mean	Std. Dev.	Min	Max
QUAN (Sales quantity)	1.085	31.368	0.000	2,206.000
ID_CV (Incoming network diversity, co-view)	1.361	1.619	0.000	15.000
ID_CP (Incoming network diversity, co-purchase)	1.673	2.191	0.000	17.500
OD_CV (Outgoing network diversity, co-view)	1.345	0.682	0.000	4.000
OD_CP (Outgoing network diversity, co-purchase)	1.557	0.914	0.000	5.000
IS_CV (Incoming network stability, co-view)	0.864	0.239	0.000	1.000
IS_CP (Incoming network stability, co-purchase)	0.718	0.344	0.000	1.000
OS_CV (Outgoing network stability, co-view)	0.842	0.238	0.000	1.000
OS_CP (Outgoing network stability, co-purchase)	0.719	0.354	0.000	1.000
LP (Product list price)	6,173.236	5,915.509	1.000	30,999.000
PV (Product review volume)	28.040	131.437	0.000	1,695.500
PR (Product review rating)	3.067	2.284	0.000	5.000
PS (Product past monthly sales quantity)	9.196	32.995	0.000	486.500
IN (Product inventory)	602.221	7,352.986	1.000	99,994.500
BM (Number of product webpage bookmarks)	185.879	767.755	0.000	10,972.500

Notes: Number of observations = 15,616; Number of products = 228; Number of days = 142.

Table A8. Descriptive Statistics (Mobile Phones)

Variable	Mean	Std. Dev.	Min	Max
QUAN (Sales quantity)	3.799	15.923	0.000	482.000
ID_CV (Incoming network diversity, co-view)	1.215	0.910	0.000	7.500
ID_CP (Incoming network diversity, co-purchase)	1.408	1.198	0.000	8.000
OD_CV (Outgoing network diversity, co-view)	1.332	0.558	0.000	4.000
OD_CP (Outgoing network diversity, co-purchase)	1.500	0.758	0.000	4.500
IS_CV (Incoming network stability, co-view)	0.823	0.270	0.000	1.000
IS_CP (Incoming network stability, co-purchase)	0.708	0.331	0.000	1.000
OS_CV (Outgoing network stability, co-view)	0.799	0.283	0.000	1.000
OS_CP (Outgoing network stability, co-purchase)	0.703	0.366	0.000	1.000
LP (Product list price)	749.580	976.975	1.000	5,280.000
PV (Product review volume)	230.909	960.165	0.000	8,211.500
PR (Product review rating)	2.729	2.348	0.000	5.000
PS (Product past monthly sales quantity)	101.751	384.877	0.000	3,100.000
IN (Product inventory)	927.980	8,523.731	1.000	99,999.500
BM (Number of product webpage bookmarks)	607.238	1,858.128	0.000	13,447.000

Notes: Number of observations = 17,195; Number of products = 238; Number of days = 138.

Table A9. Descriptive Statistics (Cosmetic Products)

Variable	Mean	Std. Dev.	Min	Max
QUAN (Sales quantity)	1.107	6.597	0.000	272.000
ID_CV (Incoming network diversity, co-view)	1.153	0.763	0.000	8.000
ID_CP (Incoming network diversity, co-purchase)	1.529	1.171	0.000	9.000
OD_CV (Outgoing network diversity, co-view)	1.364	0.604	0.000	4.000
OD_CP (Outgoing network diversity, co-purchase)	1.856	0.923	0.000	5.000
IS_CV (Incoming network stability, co-view)	0.783	0.294	0.000	1.000
IS_CP (Incoming network stability, co-purchase)	0.679	0.344	0.000	1.000
OS_CV (Outgoing network stability, co-view)	0.747	0.314	0.000	1.000
OS_CP (Outgoing network stability, co-purchase)	0.657	0.393	0.000	1.000
LP (Product list price)	65.734	53.465	1.000	499.500
PV (Product review volume)	46.613	166.842	0.000	2,700.000
PR (Product review rating)	3.880	1.815	0.000	5.000
PS (Product past monthly sales quantity)	14.478	52.794	0.000	1,169.500
IN (Product inventory)	110.757	433.525	1.000	9,978.000
BM (Number of product webpage bookmarks)	67.528	248.560	0.000	4,050.000

Notes: Number of observations = 53,061; Number of products = 722; Number of days = 111.

Estimation Results Based on Subcategories of the Main Sample of Digital Cameras

Table A10 presents the model estimation results based on all the six subcategories of our main sample of digital cameras. The results show that the product network's impact is more influential for the SLR camera subcategory, compared to all other subcategories. Noteworthy, we include all the six subcategories, rather than only the SLR camera subcategory, in our empirical analysis because the product network may connect across different categories. Thus, it is more complete and accurate to analyze the entire network (and thus all the subcategories).

Table A10. Model Estimation Results (Subcategories)

Variable	(1) Preferred (All)	(2) Subcategory (Accessory)	(3) Subcategory (Battery)	(4) Subcategory (Compact camera)	(5) Subcategory (Flash)	(6) Subcategory (Lens)	(7) Subcategory (SLR camera)
ID_CV	-0.001	-0.002	0.000	-0.003*	0.002	-0.001***	0.025***
(Incoming, diversity, co-view)	(0.003)	(0.003)	(0.007)	(0.002)	(0.004)	(0.000)	(0.006)
ID_CP	0.010***	-0.002	-0.001	-0.000	0.003	-0.000	0.019***
(Incoming, diversity, co-purchase)	(0.001)	(0.002)	(0.004)	(0.001)	(0.005)	(0.000)	(0.003)
OD_CV	-0.003	0.005	0.001	0.006	0.001	0.000	-0.000
(Outgoing, diversity, co-view)	(0.004)	(0.004)	(0.008)	(0.003)	(0.005)	(0.001)	(0.013)
OD_CP	-0.008***	0.001	0.002	-0.001	0.003	0.000	-0.008***
(Outgoing, diversity, co-purchase)	(0.002)	(0.002)	(0.005)	(0.001)	(0.003)	(0.000)	(0.003)
IS_CV	0.005	0.002	0.002	-0.001	0.004	0.000	-0.003
(Incoming, stability, co-view)	(0.003)	(0.004)	(0.009)	(0.002)	(0.006)	(0.001)	(0.009)
IS_CP	-0.000	-0.004	0.009	-0.001	-0.002	0.000	0.006
(Incoming, stability, co-purchase)	(0.003)	(0.004)	(0.008)	(0.002)	(0.003)	(0.000)	(0.007)
OS_CV	0.006	0.006	0.012	0.000	0.003	-0.000	0.011
(Outgoing, stability, co-view)	(0.004)	(0.004)	(0.011)	(0.003)	(0.006)	(0.001)	(0.011)
OS_CP	-0.017***	-0.006	-0.006	0.001	-0.000	0.001	-0.021***
(Outgoing, stability, co-purchase)	(0.003)	(0.004)	(0.008)	(0.002)	(0.005)	(0.001)	(0.006)
Constant	0.323***	0.000	0.000	0.000	0.000	0.000	0.320***
	(0.046)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.063)
Control variables	-included-	-included-	-included-	-included-	-included-	-included-	-included-
Number of observations	41,379	19,260	2,147	3,069	907	11,095	4,901
R^2	0.4934	0.7472	0.9218	0.9528	0.0171	0.9656	0.8586

Notes: Standard errors in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

Interaction Effect

Table A11 presents the results of the preferred model with the inclusion of interaction terms between network stability and product vintage, and between network stability and product past monthly sales quantity. As seen in Column (2), there exist significant interaction effects between network stability and product vintage (*IS_CV * VT*), and between network stability and past monthly sales quantity (*IS_CV * PS*, *IS_CP * PS*, *OS_CP * PS*). However, the focal estimates for network diversity and stability are similar to those in Column (1).

Table A11. Interaction Effect

Variable	(1) Preferred	(2) Interaction
ID_CV (Incoming, diversity, co-view)	-0.001 (0.003)	0.001 (0.003)
ID_CP (Incoming, diversity, co-purchase)	0.010*** (0.001)	0.006*** (0.001)
OD_CV (Outgoing, diversity, co-view)	-0.003 (0.004)	-0.002 (0.004)
OD_CP (Outgoing, diversity, co-purchase)	-0.008*** (0.002)	-0.005*** (0.002)
IS_CV (Incoming, stability, co-view)	0.005 (0.003)	0.007 (0.005)
IS_CP (Incoming, stability, co-purchase)	-0.000 (0.003)	-0.001 (0.004)
OS_CV (Outgoing, stability, co-view)	0.006 (0.004)	0.006 (0.006)
OS_CP (Outgoing, stability, co-purchase)	-0.017*** (0.003)	-0.011** (0.005)
*IS_CV * VT*		-0.000*** (0.000)
*IS_CP * VT*		0.000 (0.000)
*OS_CV * VT*		-0.000 (0.000)
*OS_CP * VT*		0.000 (0.000)
*IS_CV * PS*		0.013*** (0.001)
*IS_CP * PS*		-0.006*** (0.000)
*OS_CV * PS*		-0.000 (0.000)
*OS_CP * PS*		-0.004*** (0.000)
Constant	0.323*** (0.046)	0.319*** (0.046)
Control variables	-included-	-included-
Number of observations	41,379	41,379
R^2	0.4934	0.5053

Notes: Standard errors in parentheses. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.
VT: product vintage. *PS*: product past monthly sales quantity.