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A Dynamic Agent-Based Analysis for the Environmental Impacts of Conventional and Novel Book Retailing

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The dynamics of an e-commerce market and the associated environmental impacts from a bottom-up perspective using an agent-based model is explored. A conceptual meta-theory from psychology is adopted to form the behavioral rules of artificial consumers choosing different methods of buying a book, including conventional bookstores, e-commerce, and a proposed self-pick-up option. Given the energy and emissions savings that result from a shift to e-commerce from bookstore purchase, it appears that reductions in environmental impacts are relatively probable. Additionally, our results suggest that the shift to e-commerce is mainly due to the growth of Internet users, which ties energy and emissions savings to Internet penetration. Moreover, under any scenario, the energy and emissions savings will be provided by the introduction of the proposed self-pick-up option. Our model thus provides insights into market behaviors and related environmental impacts of the growing use of e-commerce systems at the retail level, and provides a basis for the development and implementation of more sustainable policies and practices.

Introduction

The increasing integration of information and communication technology (ICT) in contemporary society introduces substantially greater complexity to sustainability in various aspects and scales. One example is the development of electronic commerce (e-commerce) and the associated environmental impacts. E-commerce changes retail market structures dramatically across firms, industries, and economies, with more efficient logistics and lower direct environmental impacts in many cases (*1*−*3*). However, some studies have suggested the possibility of increased environmental impacts resulting from rebound effects on transport and indirect effects such as increased consumer buying power (*4*−*6*). Books are among the commodities for which e-commerce systems have proved popular; according to the U.S. Census Bureau, online book sales increased from 0.65 in 1998 to 3.95 billion U.S. dollars in 2005 (*7*). In the same period, total book retail sales were stable at around 25 billion dollars. Thus, the online proportion of total book retail sales increased from 2.46% in 1998 to 15.40% in 2005. Not surprisingly, a number of researchers have been studying this market from various aspects. For example, Brynjolfsson and Smith found that, from February 1998 to May 1999, the price of books on the Internet was 9−16% lower than that in conventional bookstores, and that Internet retailer prices differed by an average of 33% (*8*). The environmental implications of e-commerce in books have also been explored by various scholars. Matthews et al. assessed the economic and environmental impacts of e-commerce for book retailing and found that the logistics cost and environmental impacts of e-commerce are lower if considering unsold book returns in the conventional retail model (*9*). In another study, Matthews et al. found that e-commerce is not always the most efficient model in terms of economic cost and energy consumption. Population density and number of books per order can significantly change the results (*10*). In a companion article of our research, Kim et al. propose a new e-commerce model with a self-pick-up strategy and show its environmental benefit compared with the conventional e-commerce model (*11*).

These previous studies all modeled the book retail market using "top-down" linear methods, and relied on historical statistical data to describe and explore the characteristics of the book retail market. However, the book retail market, like other complex real world phenomenon, is not a static and simple system. It contains heterogeneous consumers and different options to buy books, which generates complicated and dynamic market patterns. In order to explore the complexity and dynamics of the book retail market and its environmental implications going forward, we have therefore chosen an agent-based modeling (ABM) technique. ABM is regarded as one of the most powerful computational tools in the research of complex systems (*12*). In particular, in ABM a system is modeled as a collection of agents each of which individually assesses its situation and makes decisions on the basis of a set of rules. Amazingly, even a simple agent-based model can generate valuable information about the complex dynamics of the real world system and lead to the emergence of unanticipated collective behaviors (*13*). Owing to computers, repetitive competitive interactions between agents can represent dynamics of real world systems out of the reach of pure mathematical methods (*14, 15*). ABM has already been applied to study the dynamics of retail markets from various perspectives. For instance, Tsvetovatyy et al. proposed an agent-based virtual market including all elements required to simulate a real market (*16*). Janssen and Jager developed an agent-based model to study the market dynamics from the perspective of lock-in effect (*17*), psychological variations (*18*), introduction of environmental-friendly products (*19*), and social networks (*20*). Alkemade and Castaldi investigated the diffusion of innovations on social networks using ABM (*21*).

In this article, an agent-based model is developed particularly for the U.S. book retail market to understand the market dynamics and the associated environmental impacts. To our knowledge, this is the first attempt to apply the method of ABM in decision-making for this field. The model, containing various agents (artificial consumers) and certain set of products (different options to buy books) with emergent market dynamics generated from decisions made by each individual agent choosing among different options, is calibrated and validated using the historical data on the U.S. book retail market from 1998 to 2005 (*7*) involving two options, conventional bookstores and e-commerce. Future dynamics of the book retail market and associated environmental impacts are then simulated for the mix of these

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two options as well as an introduction of the customer pick-up sites as proposed by the companion article (*11*).

Materials and Methods

The market contains consumers and two options to buy books, physically going to bookstores or making the purchase online with direct delivery. The two options differ from each other on two relevant dimensions, price and convenience. Consumers are embedded in social networks with specific structures consisting of a number of "friends. The "small-world" model proposed by Watts and Strogatz (*22*) identifies the two relevant characteristics of social networks, the small-world effect and the clustering effect (*23*), and it is therefore used in this study. In particular, agents in the "small-world" network are connected with their four nearest neighbors and randomly to each possible other agent by a certain probability. At each time step, consumers have a certain probability of buying a book. Some consumers have Internet access, while others do not. Only those who have Internet access are able to choose between the two options, while consumers without Internet access can only take the bookstore option.

The choice between the two options depends on the comparative satisfaction gained by consuming the particular option. The "need satisfaction" of a consumer consists of two components: individual satisfaction and social satisfaction. Individual satisfaction depends on the personal taste for the particular purchase option. In the model, each consumer has specific values associated with each dimension (price and convenience) of the purchase option. The individual satisfaction is defined as,

$$N_{p,i} = 1 - \sqrt{\frac{(p_{p,i} - d_p)^2 + (p_{c,i} - d_c)^2}{2}} \quad (1)$$

where $N_{p,i}$ denotes the individual satisfaction of consumer i; $p_{p,i}$ and $p_{c,i}$ are the preferred characteristics for price and convenience, respectively, of consumer i; and d_p and d_c are dimensions of price and convenience, respectively, of the purchase option chosen by the consumer i. Particularly, $p_{p,i}$, $p_{c,i}$, d_p, and d_c are dimensionless. By normalizing them between 0 and 1, $N_{p,i}$ also has dimensionless value between 0 and 1. In this research, consumers' preferences for price and convenience are endogenetic together with dimensions of price and convenience for bookstores. The dimensions for e-commerce are calibrated using historical data.

The social satisfaction depends on how popular the chosen option is in the consumer's social network. The popularity of the chosen option is not only influenced by its market share in the consumer's social network but also leadership powers of neighbored friends. In particular, the social satisfaction can be defined as,

$$N_{s,i} = \frac{\sum l_{j,i}}{\sum l_j} \quad (2)$$

where $N_{s,i}$ is the social satisfaction of consumer i; l_j denotes the leadership power of the consumer's neighbored friends; and $l_{j,i}$ is the leadership power of neighbored friends choosing the same option as the consumer i.

Therefore, the total need satisfaction can be expressed by,

$$N_i = w_i N_{s,i} + (1 - w_i) N_{p,i} \quad (3)$$

where N_i denotes the total need satisfaction of consumer i; and w_i weights the influence of social satisfaction and individual satisfaction.

Besides the need satisfaction, consumers' cognitive choice also depends on the stability of the market environment. An unstable environment may cause unexpected consequences of consumers' choice. Therefore, uncertainty is defined as the difference between the expected and actual need satisfaction. In particular,

$$U_i = \sqrt{(N_{i,t} - N_{i,t-1})^2} \quad (4)$$

where U_i denotes the uncertainty consumer i confronted in the market; and $N_{i,t}$ and $N_{i,t-1}$ are the consumer's current need satisfaction and the one at the previous step.

Each consumer has specific thresholds of need satisfaction and uncertainty, denoted by $N_{\min}$, minimum need satisfaction, and $U_{\max}$, maximum uncertainty. Given the values of N_i and U_i for each consumer, four types of cognitive processes can be defined including (1) repetition ($N_i \cdot N_{\min}$; $U_i \leq U_{\max}$), the consumer will habitually choose the option chosen at previous stage; (2) deliberation ($N_i < N_{\min}$; $U_i \leq U_{\max}$), the consumer will evaluate the expected N_i of each option, and choose the one has the highest value; (3) imitation ($N_i \cdot N_{\min}$; $U_i > U_{\max}$), the consumer will choose the option which has the highest market share, which is equal to social satisfaction, $N_{s,i}$, in its social network; and (4) social comparison ($N_i < N_{\min}$; $U_i > U_{\max}$), the consumer will choose the option which has the highest $N_{s,i}$ in its social network and the expected N_i is not lower than the current satisfaction. If no option satisfies this criterion, the consumer will choose the option having the highest expected N_i. In the rare event of multiple available and equivalent choices in each cognitive process, selection is assumed to be random.

The environmental impacts associated with the purchase of books happen in every phase of the supply chain. In particular, local transportation has been proved to be responsible for about 38.8% of energy consumption, 76.2% of air pollutants, and 40.3% of greenhouse gas (GHS) emissions in conventional bookstore supply chain. For e-commerce supply chain, local delivery is responsible for about 52.4% of energy consumption, 52.9% of air pollutants, and 53.0% of GHS emissions (*9*). In the study reported here, only the environmental impacts caused by local transportation, either driving to and from bookstores or delivering books ordered online, are addressed. Details about the computation of environmental impacts are available in the Supporting Information.

Calibration and Validation

ABM differs from conventional modeling methods in various ways such as bottom-up perspective, heterogeneous agents, or networked interactions. Particularly, a fundamental difference exists in the way that ABM breaks down general equilibriums which are primarily pursued by conventional methods. This feature of ABM brings a big challenge in model calibration and validation. For example, ABM always involves much higher degree of freedom than conventional methods owing to the heterogeneity. On the other hand, the heterogeneity of ABM ensures that the model is able to represent a high level of complexity of the real-world system. Therefore, there is a tradeoff between the decrease of the degree of freedom and the increase of the model's ability in representing real-world complexity. In fact, debates have just been raised on calibrating and validating ABM with empirical data (e.g., *24*). Although no standard technique has been developed, in this research, we are able to calibrate and validate the model with historical data in a classical statistical way. Despite the fact that the calibration and validation performed in this research are relatively poor from a statistical point of view given three parameters are fitted essentially with only eight samples, this is the best we can do at this point to

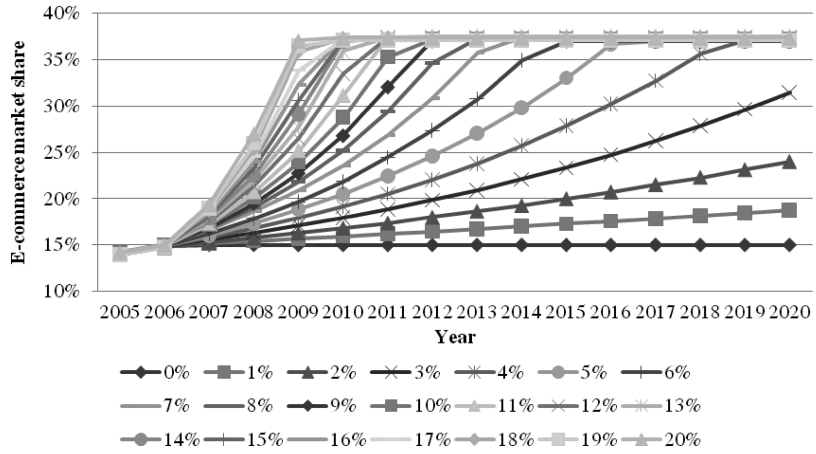

FIGURE 1. E-commerce market share from 2005 to 2020 with respect to different annual growth rates of Internet users.

reduce the degree of freedom without losing significant complexity of the model. Improvements on the statistical calibration are possible in future research by two means. First, quarterly or monthly statistics of the book retail market could enrich the historical samples dramatically. Second, characteristics of the book retail market other than market shares could be used to calibrate parameters.

In particular, there are three parameters in the model to be calibrated, the standard deviation of consumers' preference distribution, and the price and convenience dimensions of the e-commerce option. The calibration process consists of finding the values for all parameters that enable the model to replicate the historical e-commerce market share data of the U.S. from 1998 to 2005. The calibration experiment found that, in order to gain minimal squared residuals in fitting the historical data, the price and convenience dimensions of e-commerce should be around 0.85 and 0.55, respectively, while the standard deviation of consumers' preference distribution should be 0.3. The details about parameter configuration and statistical calibration can be found in the Supporting Information.

To validate the chosen parameter combination, first, the development pattern of simulated e-commerce market share fits the actual pattern. The price dimension of e-commerce, 0.85, means that the average price of books sold online is about 85% of that in bookstores, which is confirmed by Brynjolfsson and Smith (*8*). The model replicates the historical U.S. e-commerce market share except for 1999, 2000, and 2001, when the book retail market was turbulent due to the emergence of e-commerce. Therefore, there must be some exogenous variables influencing the market in these years which disappear once the market establishes a dynamic equilibrium, a point the U.S. book retail market seems to have achieved after 2001. Those variables, not captured in this model, might include factors such as price-related loss leader marketing programs, periods during which consumers "practice" with new and unfamiliar technologies before determining how they will utilize them going forward, and stabilization as initial offerings are tailored by e-commerce providers based on consumer response and feedback. However, equilibrium conditions seem to have been established after 2001, and the model simulation fits the historical data after this point. We are therefore comfortable that our model describes the performance of the U.S. book retail market and can be applied to understand the general development of this market and the associated environmental impacts.

Future Market Dynamics and Environmental Impacts

The time scale in this research is from 2005 to 2020. By doing this, the dynamics of the book retail market and associated environmental impacts can be fully explored under the condition that bookstores are competing with e-commerce either with or without the introduction of the proposed self-pick-up program. It is obvious that the real market is far more complex than this simulation. For example, the electronic books may gain a great deal of market share by 2020. However, it is far beyond our purpose in this research and the model will become more complicated if including all other factors. Therefore, the following analysis will use the simulation from 2005 to 2020 with a concentration on the near future from 2005 to 2010. Moreover, the companion paper also showed that packaging and storage are not significant in the life cycle of book retailing in terms of both economic costs and environmental impacts (*11*). Therefore, in this research, we only focus on the local delivery of books purchased by different options.

Competition between Conventional Bookstores and E-Commerce. Without a doubt, the growth of Internet users is a significant driving force for the development of e-commerce. Figure 1 shows the e-commerce market share from 2005 to 2020 with respect to different Internet user growth rates. Higher growth rates will generate higher market share for e-commerce. However, the market will reach the same equilibrium no matter what the Internet user growth rate is. When all consumers have Internet access, e-commerce has about a 37% market share in terms of sales volume while bookstores take the rest, 63%. The higher the Internet user growth rate is, the earlier the market will reach equilibrium. If the annual growth rate is higher than 12%, the market will reach equilibrium by 2010.

As long as all consumers eventually have Internet access, the market will reach equilibrium. However, the process of Internet adoption is not linear. This process, so-called diffusion of innovations (*25*), is typically evidenced by the S-shaped logistic pattern. The growth of Internet users in the U.S. is already in the "later adoption" period which has about an annual growth rate of 1% after 2004 (*26*). In the scenario developed in our model, through 2020, almost all consumers make their purchase decision based on the repetition and deliberation processes, which indicates that the market is stable. In particular, the increase of deliberating consumers causes the growth of e-commerce's market share.

At each time step, the total number of books purchased is different, as well as the total environmental impacts. Therefore, the average environmental impacts caused by the transaction of one book are chosen as the unit function. In particular, the growth of e-commerce will reduce the average transportation distance, calculated by dividing the total travel distances by the total number of books sold, of the purchase of one book from 4.65 km to 3.62 km at equilibrium because local delivery trips are on average shorter than individual

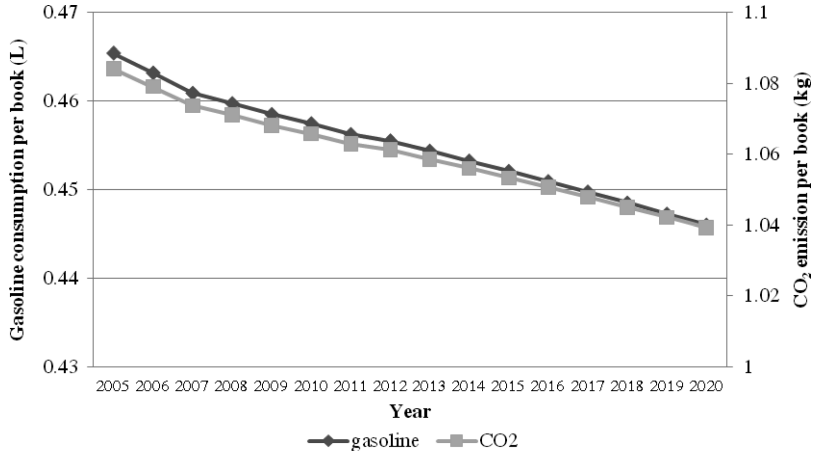

FIGURE 2. Gasoline consumption and CO_2 emissions while the annual Internet user growth rate is 1%.

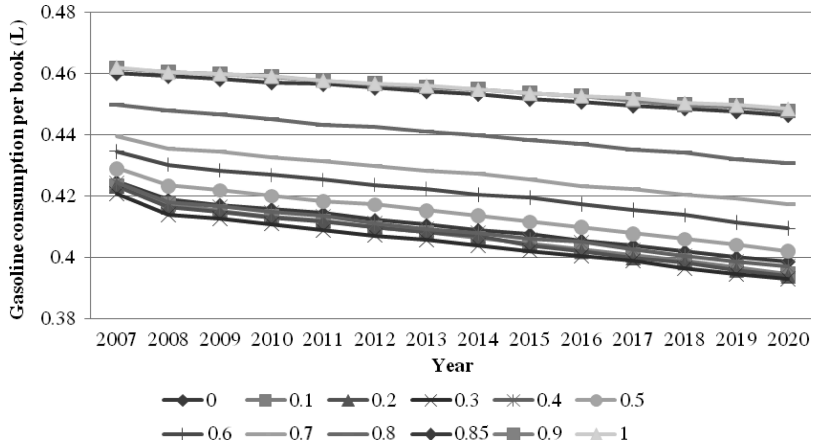

FIGURE 3. Gasoline consumption per book with respects to different values of the self-pick-up option's price dimension while keeping its convenience dimension the same as e-commerce.

drives. The reduction of gasoline consumption and CO_2 emissions associated with the purchase of one book due to the development of e-commerce with 1% annual Internet user growth rate is about 0.28% annually. If the quantity of books sold stays the same as in 2005, which is a conservative estimation (at least in the short term while book consumption and production technologies are relatively stable), the total reduction for gasoline consumption and CO_2 emissions from 2005 to 2010 are 8.51 million cubic meters (m^3) and 19.84 million tons, respectively. For the long-term from 2005 to 2020, the total reduction of gasoline consumption and CO_2 emissions are 22.41 million m^3 and 52.22 million tons, respectively. The annual reduction potentials are 1.43 million m^3 for gasoline and 3.33 million tons for CO_2, respectively (see Figure 2).

Introduction of the Self-Pick-up Option. The self-pick-up program allows consumers to pick up books they ordered online in nearby grocery stores on their way to buy groceries. As discussed in the companion paper, this proposed option could offer consumers lower price, avoid extra transportation, and thereby reduce environmental impacts (*11*). To better understand the dynamics of the market with the self-pick-up option introduced in 2007, an annual Internet growth rate of 1%, close to the actual growth rate after 2004, is chosen to conduct simulation experiments.

The transformation of the book retail market by the introduction of the self-pick-up option is studied from the aspects of the proposed option's price dimension and convenience dimension. First, Monte-Carlo simulations are conducted by varying the proposed option's price dimension while keeping its convenience dimension the same as e-commerce. Owing to the price incentive, the model results indicate that the self-pick-up option will take about 10 and 15% of the market in 2020 if its price dimension is lower than that of e-commerce by 6 and 18%, respectively. However, the maximal market share the proposed option can possibly reach is about 21% even the price dimension drops to near zero. On the other hand, if the price incentive of the self-pick-up option is effective, e-commerce's market share in 2020 will be reduced from about 19% to 10 or 5%, depending on the level of the incentive. Moreover, the self-pick-up option attracts consumers both from e-commerce and bookstores. As a result, the environmental impacts are reduced by the introduction of the self-pick-up option. In particular, the gasoline consumption and CO_2 emissions per book can be reduced by as much as 12.4% annually (e.g., Figure 3).

Second, similar Monte-Carlo simulations are conducted by varying the self-pick-up option's convenience dimension while keeping its price dimension the same as e-commerce. The self-pick-up option will not take any significant market share unless its convenience dimension is lower than (i.e., more preferable to) e-commerce's. However, the maximal market share the proposed option can possibly reach in 2020 is only about 11.5%. E-commerce's market share will be reduced to about 10% when the self-pick-up option is perceived as more convenient. The convenience-driven self-pick-up option reduces environmental impacts only by about 5% annually in terms of gasoline consumption and CO_2 emissions per book. Figure 4 shows that the self-pick-up option reaches the maximal market share in 2020, 23.7%, if the two dimensions are both around 0.25. In particular, the gasoline consumption and CO_2 emissions by per book in 2020 when both dimensions are 0.25 will be 0.38 *L* and 0.89

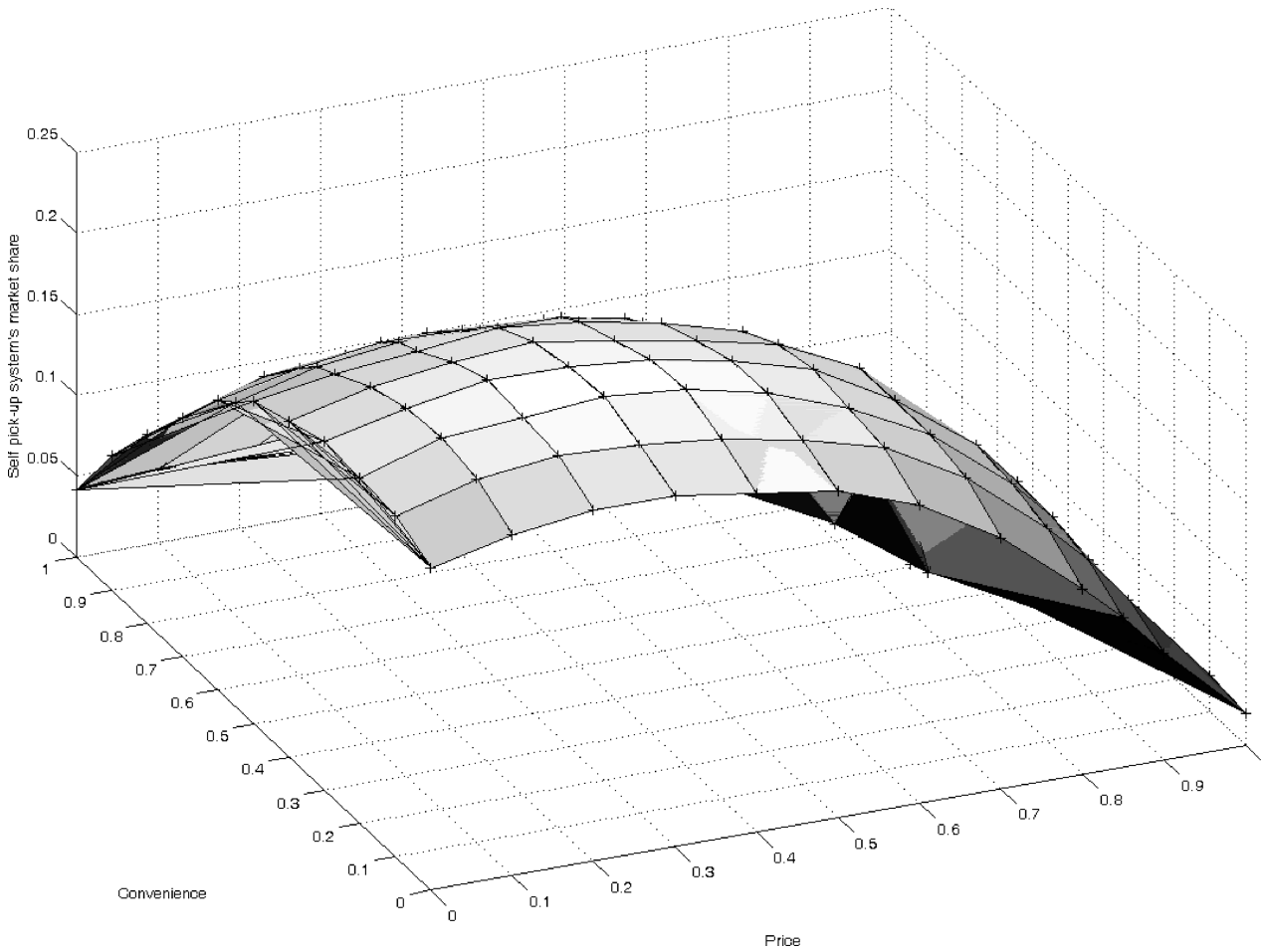

FIGURE 4. Self-pick-up option's market share in 2020 with respects to different combinations of price and convenience dimensions.

kg, respectively, which are about 85.2% of the amount without the introduction of the proposed option.

According to the companion paper (*11*), the self-pick-up option can provide a slight price incentive compared with e-commerce. Moreover, it is reasonable, and also conservatively, to assume that the proposed option is slightly less convenient than e-commerce because consumers must at least make extra effort to pick the book up at the pick-up site. Accordingly, we conducted Monte-Carlo simulations to study the success of the proposed option given price and convenience dimensions of 0.80 and 0.60, respectively. Similar with the previous model runs, consumers make their purchase decision mainly based on repetition and deliberation, and the market comes back to stability very soon after the introduction of the proposed option. The results suggest that bookstores maintain a share of 81.0% in 2020, the same as the scenario without the introduction of the self-pick-up option. However, the market share of e-commerce in 2020 is about 12.3% which is lower than that in the absence of the proposed option, 19.0%. The remaining 6.7% share is taken by the self-pick-up option in 2020. Moreover, under this scenario the introduction of the self-pick-up option reduces gasoline consumption per book to 0.44 *L* and CO_2 emissions per book to 1.02 kg in 2020. While this may not seem very impressive if comparing with 0.45 L gasoline and 1.04 kg CO_2 per book in the case of without the proposed option, it is important to remember that more substantial reductions of environmental impacts are possible if Internet use grows faster, the price differential between the self-pick-up option and alternatives increases, or consumers attribute more convenience than we did to the self-pick-up option.

The above analysis assumes that all consumers are aware of the self-pick-up option as soon as it is introduced. However, it is probable that at least some of the consumers will be aware of this option only after a time lag. In particular, the more quickly consumers know about the self-pick-up option, the higher market share it will get. However, there is an upper limit to the market share that the self-pick-up option can possibly reach, which depends not on the degree of consumer awareness, but only on the price and convenience characteristics of the new system as discussed before. Details about effects of consumer awareness can be found in the Supporting Information.

Sensitivity Analysis

Sensitivity analysis is conducted to see how parameters affect the model outcome. First, the size of consumers' social networks, indicated by the probability of randomly connecting with non-neighbor agents, is altered to study the effect of social networks on model outputs. In general, the more links the network has, the larger it is and the faster information can be spread. The analysis found that it is hard to find a single parameter combination whose output can generally fit the historical data, if the size of consumers' social network is reduced by changing the connecting probability from 1 to 0%, or, alternatively, to 10% indicating a larger network. Apparently, smaller or larger social network cannot generate statistically stable model outputs. The small-world network with 1% connecting probability, also studied by Janssen and Jager (*18*), thus proves best able to represent the actual social network in our research.

Additionally, we study the effects of heterogeneity in consumers by running counterfactual scenarios that artificial consumers are modified to be homogeneous. Under the same configuration in the calibration experiment, the squared

residuals in the homogeneous model are 2 or 3 orders of magnitude higher than those in the heterogeneous model, which is even worse than the results of changing the size of consumers' social networks. The higher uncertainty of the homogeneous model suggests that heterogeneity is a necessary feature for our model to properly simulate the real-world complexity.

Moreover, the effects of endogenetic parameters, including consumers' leadership power, weight of social need, minimum need satisfaction, and maximum uncertainty, on the model outcome have also been studied. Originally, these parameters were drawn from a uniform distribution between 0 and 1. In the sensitive analysis, the uniform distribution is replaced by a normal distribution normalized between 0 and 1. In particular, the squared residuals of the calibration in the normal-distributed model have the same magnitude with those in the uniform-distributed model, which suggests that these four parameters are relatively less sensitive for the model outcome. However, note that the underlying interaction among consumers in this model is characterized by these parameters in a very simple way. In reality, for example, "leaders" may tend to weigh individual satisfaction more than other consumers in the same social network. Furthermore, consumers in a smaller network may be more satisfied and less uncertain than those in a larger and more dynamic network. Although taking these parameter interactions into account will make it too complicated for this research, future study should be able to improve the model by including such interactions among parameters.

Discussion

Although the market share of the self-pick-up option varies under different scenarios, there is always a maximum it can reach. This phenomenon reflects the lock-in effect in the real market. The lock-in effect, which describes the fact that one or several particular vendors may dominate the entire market and create substantial barriers for other vendors, has been explained mainly as the results of technology advancement of the leading vendors (*27*) and the cognitive interaction of consumers (*28*). In this research, the lock-in effect of bookstores, which prevents the increase of the self-pick-up option beyond a certain limit, is primarily due to consumers' cognitive interaction. In other words, the initial choice of a consumer and choices of his/her social network create a cognitive barrier for shifting to other options. In future research, the model will be able to more comprehensively understand the lock-in phenomenon of the real market by incorporating retailers as agents and making the cognitive pattern of consumers evolvable.

The proposed self-pick-up option must provide incentives, especially on price, to consumers to obtain significant market share. Essentially, this proposed option is a modification of e-commerce. Therefore, it will first attract e-commerce consumers, and, as a corollary, must offer price incentives as against e-commerce, as opposed to bookstore sales. Bookstore consumers will only be attracted by the proposed option if it can provide enough incentives in terms of both price and convenience. The improvement in terms of convenience is relatively difficult because the measurement is psychological and depends on consumers. Therefore, providing price incentives would appear to be the simpler and more effective approach for the self-pick-up option.

This research has a number of policy implications, especially in light of the continued increase in business-to-consumer e-commerce, which focus attention on making the underlying logistics system as efficient as practicable. Most obviously, it suggests that there are beneficial externalities to restructured local delivery systems that may warrant policies, such as incentives or subsidies, which overcome the barriers of established practice and enable more efficient alternatives. Such policies should be temporary, since their purpose is not to support otherwise uneconomic networks, but to enable the shift to new, more efficient patterns of commerce. Additionally, this case also illustrates the general principle that increased environmental and social performance, or more sustainable practices, need not to require curtailment of choice but, in fact, can arise from enhancement of choice: consumers adopt the self-pick-up option not because they are required to, but because they choose to. This is an important implication because so much of the current environmental and sustainability policy portfolio is based on restricting choice, which is always politically difficult. This example suggests that exploring alternatives that enhance choice while supporting sustainability is an underappreciated domain of policy research. Moreover, behaviors that are chosen rather than forced may well be more resilient, at least in the short run, which is another interesting policy implication of this case, albeit one which requires more study before it can be regarded as demonstrated.

More broadly, the method used to develop this model can be applied to study market dynamics for other products and logistics systems. In fact, it might even be more powerful in some ways for those cases, because of the data limitations regarding the book market and the rapid changes in both logistics technology (e.g., e-commerce) and cultural patterns (e.g., less books read and more electronic delivery of information). Therefore, sophisticated statistical methods cannot be perfectly applied to calibrate this model. When studying market dynamics in other fields, there may be sufficient data available, and more stable technological and cultural patterns, to enable better calibration. In some ways, therefore, that this model is valuable in this case study is a rather rigorous proof of principle for its use in less challenging markets. A generalized framework can be developed based on this research and applied to the study on other products which are significantly purchased online and portable enough for combining the pick-up with daily grocery shopping.

There are several other important factors which our model does not directly address. For instance, consumers' preferences should change over time, rather than being held constant as in the model. Similarly, younger generations would tend to favor e-commerce when they have their own purchasing power. Additionally, the deployment of ICT has both positive and negative roles in reducing travel from various aspects (*29*). In this research, the proposed option may encourage extra personal travel to pick-up sites due to the rebound effects, which could significantly change the result. Moreover, given the economy-wide scale of our research, the book retail market is treated at the average level, while in reality, significant variations exist in travel methods, vehicle types, personal preferences, and product dimensions. These concerns should be included in the model in future research. What we cannot include, but recognize as major exogenous unknowns, are relevant changes in technology, from dramatically more efficient personal transportation, to electronic books and perhaps local print-on-demand outlets. As they occur, such technology shocks could be incorporated in more complex versions of our model but, as with all modeling exercises, we are generating scenarios exploring possible future options, not purporting to predict actual futures.

Supporting Information Available

Details about the methodology and analysis. This material is available free of charge via the Internet at http://pubs.acs.org.

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