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SMART Handout: An Innovative Tool to Empower Applied General Equilibrium Teaching

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Instructors of applied general equilibrium (AGE) courses usually face an important challenge: how to effectively and efficiently teach a large number of complex materials that are necessary for AGE analysis, including general equilibrium theory, producer and consumer theory, equational expression and model implementation. To overcome this challenge, in this paper we propose an innovative teaching tool, the SMART handout, which is a Wiki-style interactive handout that connects materials from AGE and several prerequisite courses and forms a knowledge network for easier cross-reference and deeper understanding. We take the Global Trade Analysis Project model as an example to demonstrate how a SMART handout is developed and applied in AGE teaching. This innovative tool can be generalized to other AGE courses, thereby contributing to building the capacity of future AGE researchers.

JEL codes: A20, A23, C68, D58

Keywords: Applied general equilibrium, Teaching tool, Economic education, SMART handout

1. Introduction and motivation for the SMART handout

Despite the wide application in public policy, international trade and sustainability research, the teaching of applied general equilibrium (AGE) analysis in an effective and efficient way remains a long-lasting challenge. As highlighted in Whalley (1986) and further emphasized by Hertel (1996) and Rutherford (2020), teaching AGE analysis presents a significant challenge because it involves a wide range of knowledge and skills, including the theory of general equilibrium, a good understanding of producer and consumer theory, the capacity to process data and program models, a good grasp of behavioral parameters estimation, the understanding of policies and the behavior of sectors to be modeled, as well as the

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capability to effectively and accurately interpret results (see Rutherford (1995) for an example). These requirements can be overwhelming, creating significant barriers for students enrolled in a graduate program of economics or applied economics. The inability to understand, use, and ultimately build AGE models and apply this knowledge after graduation limits capacity-building for the future generation of AGE researchers, thereby leading to a situation of excess demand for these skills.

With awareness of the challenges in teaching AGE analysis, researchers have made pedagogic contributions along three main dimensions: theory, implementation and pedagogy. The most conventional approach to teaching is to develop a simplified AGE model for educational purposes, which maintains the key theoretical framework, assumptions and components of larger, complex models, but remains simplified enough to be solved analytically 'with paper and pencil' (e.g. Fullerton and Ta (2017)). The analytically tractable feature of simplified models allows for transparency in the underlying mechanisms and makes the models accessible for students who are new to AGE analysis. It also helps to reduce the burden of programming skills at the starting stage of AGE learning (Fullerton and Ta, 2019).

To further bridge the mathematical form of AGE models and their numerical implementation, researchers have introduced simplified AGE models with specially designed simulation programs (Pozo-Barajas et al., 2013), excel spreadsheets (Moro-Egido and Pedauga, 2017), Python with Jupyter notebooks (Jenkins, 2022), as well as software used at the frontier of AGE research, such as in the General Equilibrium Modelling PACKage (GEMPACK) (Harrison et al., 2004), the General Algebraic Modeling System (GAMS) and its Mathematical Programming System for General Equilibrium (MPS/GE) subsystem) (Lanz and Rutherford, 2016; Markusen, 2002; Markusen, 2021; Rutherford, 1997). Furthermore, more interactive in-class activities, such as games and experiments, are also introduced to AGE courses to complement traditional "blackboard" lectures. These interactive activities are usually based on commonly researched topics, for example international trade (Johnson, 2010) and tariff setting (Winchester, 2006). Students adopt the role of different agents in the economy to facilitate understanding general equilibrium analysis from a more direct, self-interested view.

Despite these advances, there remain significant AGE teaching challenges. Although simplified AGE models and computer-based implementations help students to understand how an AGE model is built and solved on a computer, important questions are less well-addressed in standard AGE curricula. For example, why is the model built with those specific assumptions and functional forms? What are the underlying restrictions on consumer and producer behavior? Are these supported by empirical evidence? To fully understand these, and other important questions, it is not sufficient to depend solely on materials from the AGE course. This broader understanding also requires that students continuously refer to materials from several prerequisite courses on general equilibrium, microeconomic theory, and the corresponding economic and mathematical foundations (which they may or may not have previously taken). This can make the workload for a successful AGE course excessive, given the time constraints faced by the students.

These challenges are further complicated by the need for continuous interactions between the models' economic mechanisms, the mathematical expressions and their programming implementation, as well as the equilibrium interactions amongst agents and systems within the model. Those different directions and components, although intrinsically related to one another, are usually taught as segments in AGE courses, and students need to spend extra time and effort to strengthen connections on their own. This can be overwhelming and definitely raises the bar for effective AGE learning, and lead to one of two unfavorable consequences for a non-negligible proportion of the students. Some of them simply reduce their efforts to connect AGE models with economic theories and finish the course with a less solid, in-depth understanding of the material. Other students may feel frustrated or disempowered by the heavy load, and thereby are discouraged from using AGE models in the future.

In view of these challenges, this paper aims to contribute to AGE education with improved curricular materials. In particular, we focus on the role that handouts can play in economic education. (In this paper, we used the word "handout" as an umbrella term for all kinds of class notes, both hard copy and electronic forms, prepared by instructors and distributed to students). According to the National Quinquennial Survey, handouts (identified as "Instructor-developed class notes" in the survey) steadily ranked as the third most popular form of curricular materials in undergraduate economics courses from 2000 to 2020, surpassed only by textbooks and instructor-developed problem sets (Asarta et al., 2021). However, the format of handouts - usually distributed as slides or articles - remains almost unchanged despite the improvements in other dimensions of AGE teaching.

In this paper, we introduce an innovative handout that can greatly facilitate the internal connections between components of an AGE model and the external connections between the model and its theoretical foundations. This handout, labeled the "SMART handout", is an interactive electronic note that connects various concepts of AGE analysis in the style of Wikipedia. In the Fall semester of 2023, we introduced the SMART handout in the course “AGEC618: Applied General Equilibrium Analysis” (a PhD level course focusing on the Global Trade Analysis Project (GTAP) model and its applications) offered at Purdue University. The use of this handout received positive feedback from students (evaluation of usefulness: 4.22/5) as well as from researchers in the GTAP Center at Purdue University. We believe that the SMART handout, which is included in the supplementary materials for this manuscript, has shown the potential to enhance the teaching of AGE courses, and expect to keep improving it with feedback from broader applications in AGE education. Furthermore, the concept of the SMART handout could be readily generalized for use in the teaching of other topics.

This paper is organized as follows. Section 2 provides a summary of the SMART handout's theoretical background, including its origin and the five key features that make this handout SMART. Section 3 presents an example of applying the SMART handout to the teaching of the GTAP model, as well as the procedure for modifying and developing the SMART handout. Section 4 discusses the broader implications of the SMART handout for AGE teaching, its future potential and its limitations. Section 5 concludes this paper.

2. The philosophy of SMART

As its name indicates, the SMART handout can be defined through its five key features, which also establish the "philosophy of SMART". A SMART handout is a handout that contains Searchable materials, supports Multimedia content, organizes notes in an Atomistic way (as separate and self-explanatory elements of the handout), creates a Relationship between notes, and emphasizes the Theoretical foundation of these concepts. The philosophy of SMART is inspired by the Zettelkasten Method (Luhmann, 1981) (Box 1) and its well-known successor, Wikipedia, which share an outstanding capacity to connect various concepts to form a network of knowledge that can be infinitely extended. It is also rooted in the lead authors' reflections on the obstacles in graduate economics education, both from a student's and an instructor's perspectives.

Box 1: What is Zettelkasten Method?

Developed by the German sociologist Niklas Luhmann, the Zettelkasten ("slip box" in English) method is a tool of storing and organizing mutually connected information. The original form of Luhmann's Zettelkasten method is a collection of note cards. Each card consists of three parts: (1) a unique index of that card, (2) a piece of information and its connections with other cards (identified by their indexes), and (3) the source of that information. Besides those note cards, the method also contains a structural note that provides the 'big picture', i.e., key information and their relationship, as a starting point to search through the note collection. The Zettelkasten method provides a model of information system with hypertext links, which inspires similar systems in electronic form (Sascha, 2020).

Below we explain the five features of the philosophy of SMART:

Searchable contents. Compared with any handouts in hard copy (including Luhmann's own Zettelkasten!), the SMART handout shares the favorable feature with other electronic handouts that most contents in the handout are in text format and are therefore readily searchable, which provides great convenience for review by the student. Furthermore, the SMART handout provides a side panel that lists all notes, which also serves as a table of contents and allows readers to browse through material in a similar way to a traditional handout.

Multimedia materials: The teaching of economics usually involves multimedia materials, including text, equations, tables, figures, and links to external sources. All of these multimedia materials are supported with the SMART Handout. It is also worth mentioning that the SMART handout allows users to include mathematical equations using LaTeX, which is very important for the teaching of the rigorous mathematical representation of AGE models.

Atomistic notes: Atomistic notes, together with the relationship between notes, are among the most important features that distinguish a SMART handout from a traditional handout. Instead of clustering knowledge pieces as paragraphs or slides, a SMART handout keeps them in an atomistic way with the following rules: (1) for each independent concept, store it in one and only one note. Ensure that this concept's note is as self-explanatory as possible; (2) when the note of a concept relates to other concepts, avoid recording duplicated information of these concepts and refer to them with links instead; and (3) when the note of a concept becomes too long, try to identify subtopics of the note and make them new independent, atomistic notes. Following these rules, the atomistic notes can be regarded as nodes in a network and can be readily connected with links. Storing knowledge pieces with multiple atomistic notes instead of clustering them all together in long and complex articles also facilitates the possible expansion of relevant information in the future.

Relationship between notes: The importance of establishing the relationship between notes in a SMART handout is illustrated in Figure 1. A traditional handout is usually developed based on textbook materials or lecture slides. As a result, it inherits the linear flow of materials from books or slides: in each chapter, pieces of knowledge are explained one after another, resulting in the structure as a collection of parallel lines. Although those non-adjacent pieces of knowledge may still relate to each other, for example, the overall structure of an AGE model and the optimized problems to be solved by different agents (usually taught in different chapters), this parallel structure provides limited opportunities to cross-reference key concepts. This can result in fragmented understanding of knowledge in students' minds.

In sharp contrast to this linear approach, a SMART handout organizes curricular materials as a network. In this network, each (atomistic) node is connected not only with nodes from the same chapter, but also with relevant nodes from other chapters. This feature provides students with the opportunity to review relevant concepts and information much more frequently and easily compared to a traditional handout. Whenever the student has a doubt or a vague memory of a relevant note, they can test themselves first and check the answer immediately by clicking the link, which helps them to strengthen their understanding and establish a solid foundation of knowledge.

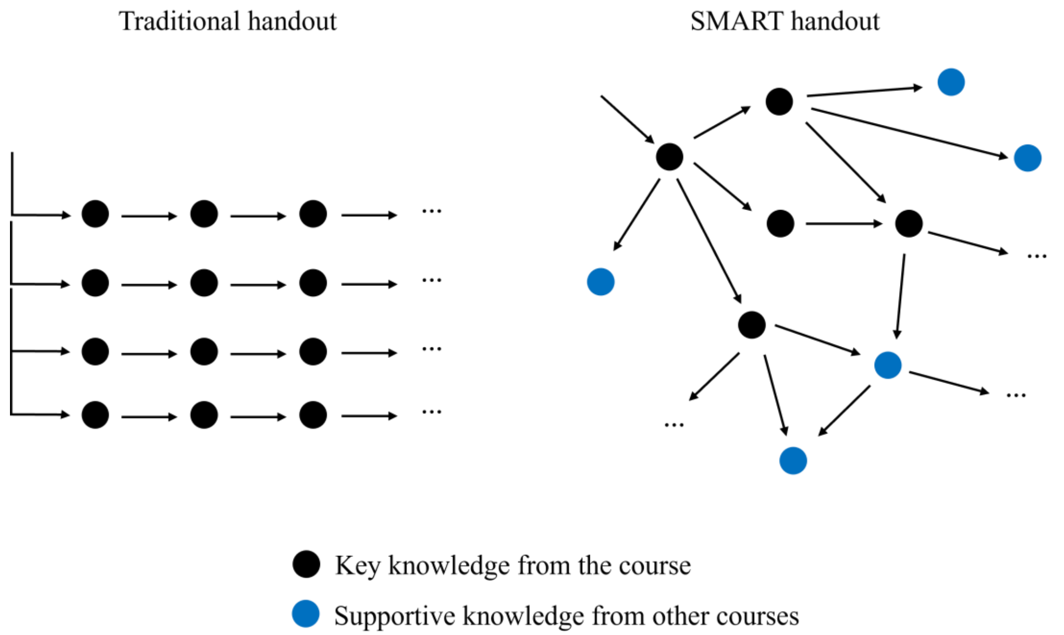

Figure 1. The structure of a traditional handout and a SMART handout.

Source: Authors' illustration.

Theoretical foundation: Finally, the traditional handout tends to mainly include materials from the current course (black dots in Figure 1), but much less supportive information from previous courses, if any (blue dots in Figure 1). In view of this, the SMART handout takes advantage of unlimited relationships between nodes to connect materials from the current course with the more fundamental concepts from other courses or sources, usually from mathematics and economic theories. This feature allows students to learn new knowledge and review previous knowledge at the same time, to achieve a deeper understanding of how complex models are established from theoretical foundations. In the next section, we will utilize these five key features of the SMART handout to provide an example of its application in AGE teaching.

3. SMART handout for GTAP: an application in AGE teaching

In order to demonstrate how to apply the philosophy of SMART in AGE teaching, here we select the GTAP model (Corong et al., 2017) as an example. The GTAP model is a multi-sector, multi-region general equilibrium model that focuses on modeling the bilateral trade between countries, as it enters national supply chains, and the interactions between these trade flows and domestic supply and demand. The inherent complexity of the GTAP model makes it a good example of the challenges we face in teaching AGE analysis to students of economics.

To facilitate the teaching of the GTAP model, we develop the SMART handout for GTAP for the course "AGEC618: Applied General Equilibrium Analysis", which is a semester-long PhD level course from which students learn the GTAP model and apply it to a research topic.[1] This SMART handout focuses on the materials offered in the first six weeks of lectures, which introduce students to a specialized version of the GTAP model that is simplified to represent a single, aggregated world region, while preserving the structure of domestic supply and demand as determined in the full-blown GTAP global AGE model.

Figure 2 provides a schematic representation of the network of concepts (represented here as nodes) and relationships (represented here as edges) from the SMART handout for the GTAP model, as well as the zoom-in view around key concepts of the course (its full-size version is available in the supplementary materials). Figure 2 shows that the nodes representing the course materials (text in black) comprise just one-third of all nodes. This finding highlights the significance of the supportive materials from other courses (text in blue in Figure 2), usually not included in traditional AGE handouts. These related concepts play an important role in the effective teaching of AGE models and, therefore, must be connected for the students to fully benefit from the instruction. Furthermore, Figure 2 identifies several hot spots of connected nodes, measured by the frequency that a node is cited in the content of other nodes. Those hot spots include both concepts from this course ("the Allen Partial Elasticities of Substitution", "Constant Difference of Elasticity", "Sets in GTAP model"), as well as fundamental but still important concepts from prerequisite courses ("Constant Elasticity of Substitution Function", "Shephard's lemma"). The density and frequency (represented by the warmer — increasingly red — color of edges) indicate that those concepts are central to teaching the GTAP model because they are frequently cited in other notes. For this reason, they should be taught with extra effort and reviewed in assignments and quizzes. This is an example of how the SMART handout can serve as a tool for instructors to use in determining the allocation of scarce teaching time.

[1] The current version of SMART handout for GTAP is developed based on the classic GTAP model (version 6.2), in order to be consistent with the existing course materials of AGEC618. We plan to develop an updated version of SMART handout to be aligned with the standard GTAP model (version 7) in the future.

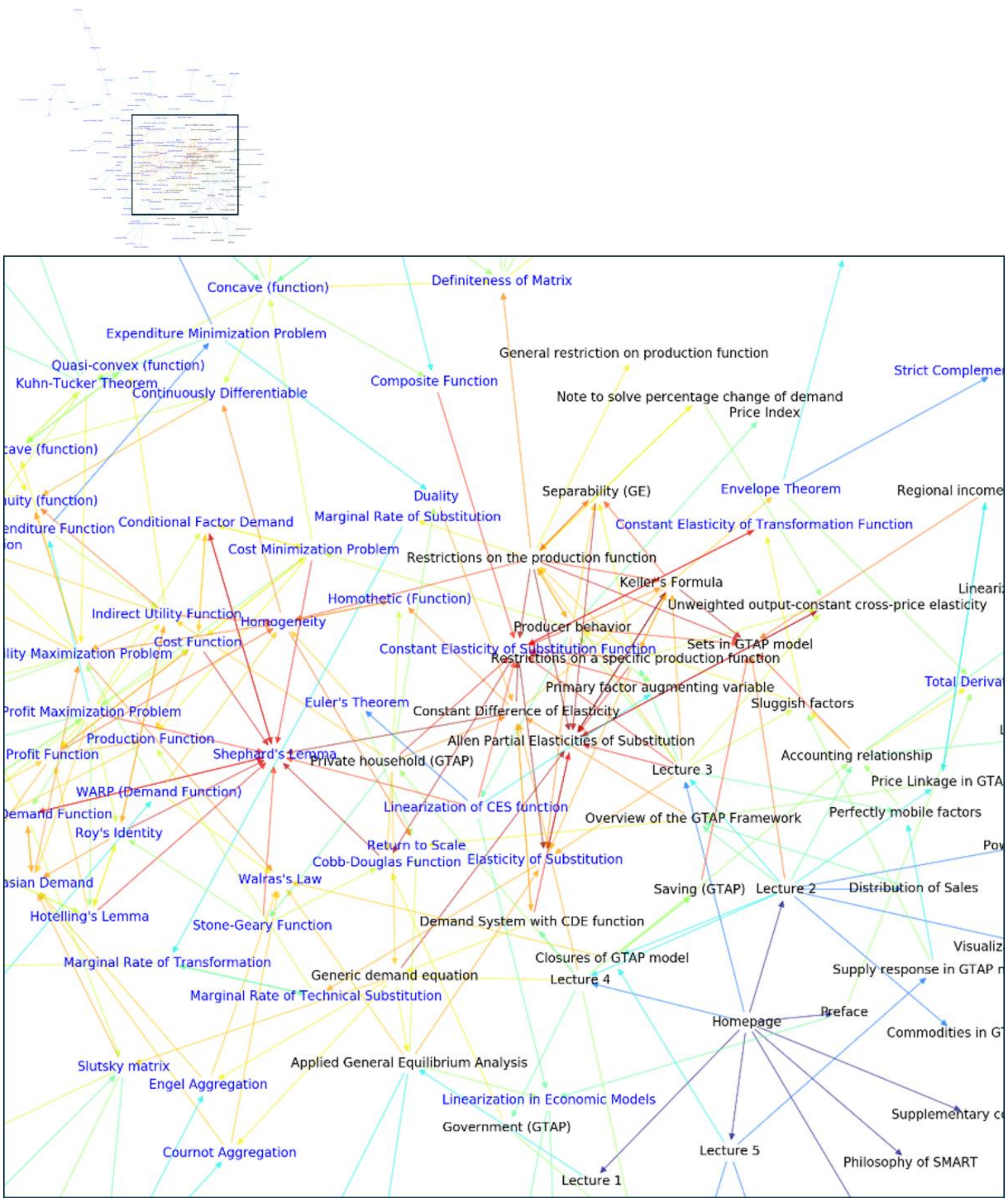

Figure 2. The knowledge network of SMART handout for GTAP and its zoom-in view.

Notes: Text on node: the corresponding note's title. Text in black: notes from the AGE course's materials. Text in blue: supportive notes from other courses or external sources. Color of edges: the sum of frequencies that two notes connected by this edge are cited in other notes, from high (warm) to low (cool).

Source: Authors' illustration.

With the big picture of the SMART handout in mind, we further provide an example of how course materials are presented and linked in the SMART handout for GTAP with screen shots of this tool (Figure 3). We regard this example as a 'teaser' for the entire knowledge network and encourage readers to download and explore the SMART handout for GTAP from the supplementary materials published with this paper (Box 2).

Box 2: How to browse the SMART handout for GTAP

The distributed version of SMART handout for GTAP is provided in the supplementary materials of this paper as a zipped file. We plan to publish future versions of SMART handout for GTAP as updates at the website of the Journal of Global Economic Analysis (https://jgea.org) and the GTAP Center (https://www.gtap.agecon.purdue.edu).

Users can download and unzip this file, open "AGEC618.html" in any internet browser (Edge, Firefox, Chrome, etc.) and access materials in the SMART handout as an offline wiki-style website. One can navigate across lectures and concepts with the side bar, jump between concepts with hyperlinks, or open multiple pages in new tabs for cross-checking.

The top panel of Figure 3 shows the structural note of the lecture on the production system in GTAP (the node "Lecture 3" in Figure 2), which summarizes key concepts in this lecture. In order to establish a solid theoretical foundation, students need to not only understand the key concept "Allen Partial Elasticity (APE) of Substitution", but also its relationship with relevant concepts: "unweighted output-constant cross-price elasticity" from the same lecture and "(full) elasticity of substitution" from previous micro-economic classes. With the SMART handout, students can click the hyperlink (text in blue) and jump to the note of each elasticity directly to check its definition and equational form, in order to deepen their understanding.

Furthermore, another key component of this lecture, the restrictions on the production function, is also linked with the note on the "Constant elasticity of substitution (CES) function", which plays an important role in AGE modeling (Rutherford, 2002). The note of CES function not only provides explanation on this specific function, but demonstrates its relationship with several other functional forms (linear, Cobb-Douglas and Leontief), connects it with a closely related concept "constant elasticity of transformation (CET) function", and also links back to the concept "elasticity of substitution." Students can navigate across notes for a quick refresher on those concepts they have learnt, or continue to explore more concepts both from this AGE course and from other supportive materials. With the relationship-based SMART handout, cross-referencing across lectures or courses is a smooth process.

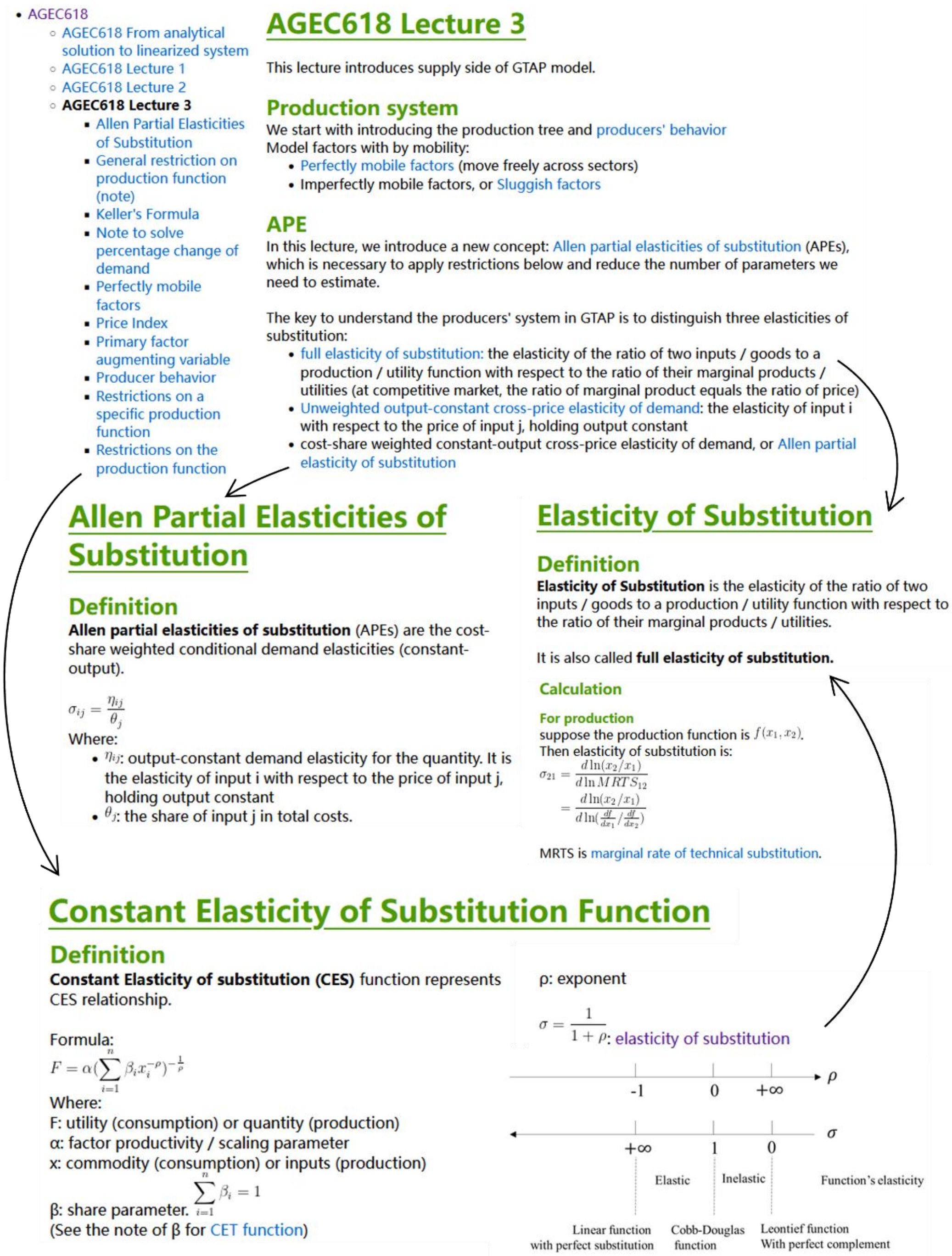

Figure 3. Example of linkages between notes.

Source: Authors' screenshots with edits.

With the example shown in Figure 3, one may wonder how the SMART handout was developed, and whether they can modify the SMART handout or even develop their own SMART handout for teaching purposes. In the development of the SMART handout for GTAP, we chose to implement the idea of the SMART handout with the graphical text editor Zim (Karssenberg, 2018), version 0.75. Zim is favored by the authors for several reasons. This software is free and open-source; it is available on Windows, Linux and macOS platforms, and it provides a portable version so you can edit your handout without having to install the software. Although it is based on the syntax of wiki markup, Zim follows the style of "What you see is what you get". It provides a very user-friendly interface for an instructor to edit or develop a SMART handout, without the requirement of typing in the specific syntax (Figure 4). Once the editing is finished, the instructor can export the SMART handout from Zim to html format and distribute it to students, and students can open the exported handout as offline webpages on any platform and get almost the identical interface as the instructor's side (the upper panel of Figure 3). Finally, instructors can enhance Zim's support for multimedia materials with various plugins, including the equation editor with LaTeX, diagram editor with Graphviz and links to reference management software such as Zotero and Mendeley. Experienced users can also create their own plugins with Python to further customize Zim to satisfy specific needs.

It is worth emphasizing that the SMART handout and its philosophy are more of a methodology than a specific piece of software. Theoretically, any software that supports hyperlinks between notes can be used to create a SMART handout. Besides Zim, instructors can also explore other alternative software, both open-source (Mediawiki, Tiddlywiki, Zettlr, etc.) and closed-source (OneNote, Notion, Obsidian, etc.). These alternatives all provide support for the features of a SMART handout, but still vary in multiple aspects of functionality and customization. For example, Obsidian differs from Zim in the syntax (markdown vs. wiki markup), the display of equations (from math expressions vs. saved as images), the language to code for plugins (Typescript vs. Python). We encourage readers to adopt the concept of the SMART handout using the software that best suits their individual teaching requirements, as long as it aligns with the principles of the SMART philosophy.

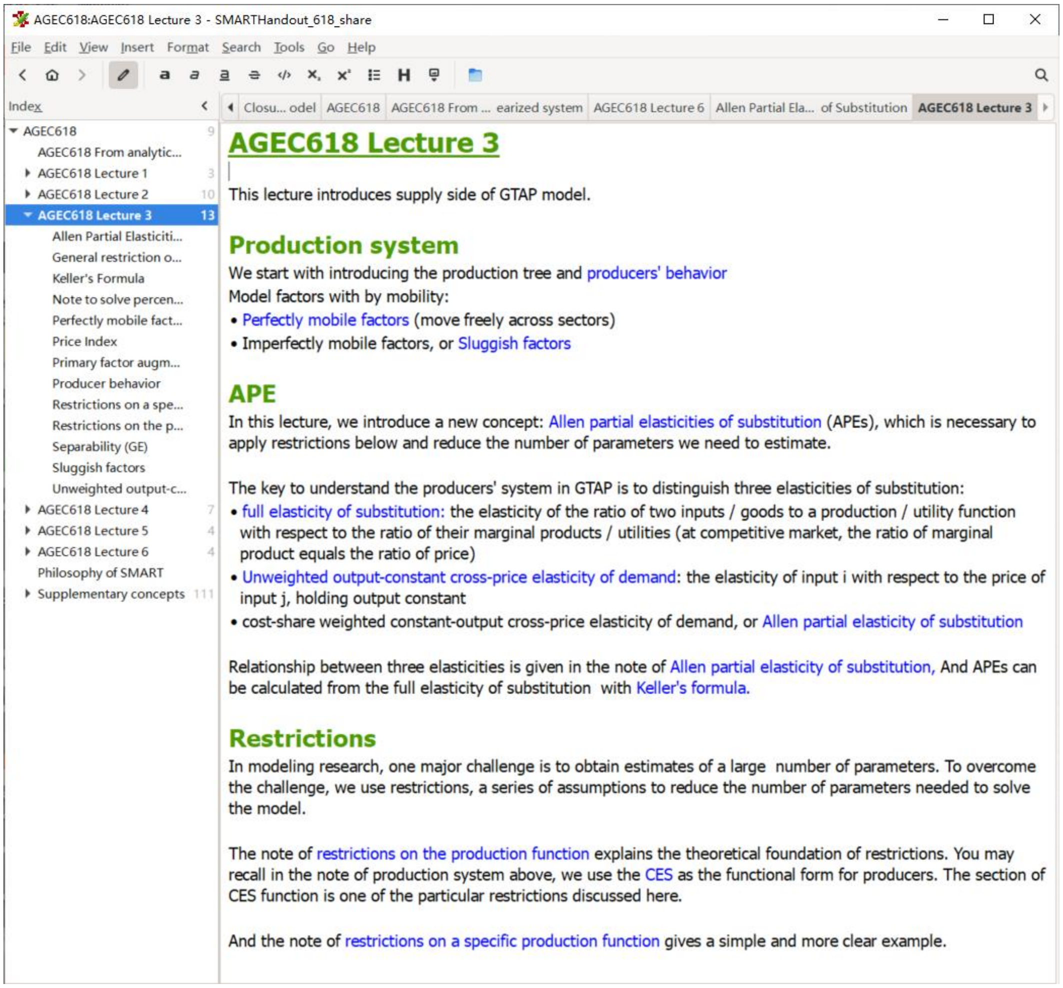

Figure 4. The editable version for instructors in Zim of the SMART handout for GTAP, lecture 3.

Source: Authors' screenshot.

4. Discussion

In this paper, we propose an innovative teaching tool, the SMART handout, which has shown good potential for facilitating the teaching of AGE analysis. We also provide an example of applying the SMART handout in the teaching of the GTAP model. With the philosophy of SMART, this innovative tool can promote students' understanding of complex AGE models by strengthening the connections between various pieces of knowledge offered from the course, as well as their relationship with supportive theoretical knowledge from other courses.

In addition to the convenience of cross-checking and connecting concepts as discussed above, the design of the SMART handout also makes it a convenient tool for active learning. It has been found that academic performance can be improved by helping students to actively recall materials they have learned with a self-test (Augustin, 2014). With a traditional handout where all materials are directly provided, students may only conduct passive recall -- merely reading the handout. In contrast, with the SMART handout, detailed concepts are masked by the link, so students can challenge themselves first by actively recalling the content of that note behind the link, and then check their memory immediately by jumping to that note with a single-click. This interactive feature of the SMART handout incorporates self-testing and recollection of key concepts as a natural component of the learning process, which helps students to learn AGE analysis more effectively.

One possible concern about the SMART handout is that, with course materials available in this readily accessible format, students may have diminished incentive to attend class. We dispute this concern from three aspects. First, the distribution of course materials outside of classes is not restricted to SMART handouts, but is faced by all kinds of handouts, even the textbook. Second, providing handouts to students may not necessarily leave a negative impact on course attendance, according to the literature review by Picault (2021). Also, in our recent teaching experience at Purdue University, we did not find this to be the case. We emphasize that the SMART handout, or any kind of handout materials, cannot replace the role of lectures and active discussions in AGE education. Instead, we regard it as a complement to, and extension of, the in-class experience.

A promising approach for combining AGE lectures and the SMART handout is 'flipped classroom'. In flipped teaching, students learn the fundamental course materials on their own before the class, which allows the students to learn at their own pace and also helps instructors to mainly focus on the deep and complex materials during lecture (Gopalan et al., 2022). In our class at Purdue University, students also submit a short homework assignment on that week's material before coming to class, so that the instructor can assess which concepts require additional attention. With the help of the SMART handout, the instructor can combine materials from various levels and perspectives. This is likely to include basic economic theories, detailed procedures for solving specific optimization problems, as well as satisfying the personalized needs of students with differing backgrounds and at differing stages in their studies. Indeed, we believe the SMART handout can greatly enhance the effectiveness of flipped teaching.

A further, important advantage of the SMART handout is its utility for distance learning of AGE (for example the GTAP University, a hybrid education platform of the GTAP model). AGE analysis has become increasingly popular in many regions of the world, but it is still challenging to deliver AGE courses in countries with limited educational resources, or even without reliable access to the internet. Also, the backgrounds of students from those distance learning courses are usually more diverse. With the help of SMART handouts, instructors can integrate both

AGE course contents and more fundamental supportive materials in an interactive way and make them available both online and offline, in order to greatly enhance AGE teaching in under-resourced settings and satisfy the needs of students with differing backgrounds.

Finally, we are aware of several limitations of the current version of the SMART handout. First, instructors may want to change the appearance of the SMART handout, but the built-in options in Zim on appearances are still limited. This problem can be solved if the instructor can work directly on the html versions with additional knowledge of webpage programming. Second, the exported html version from Zim needs to be further edited to remove unnecessary links to multimedia attachments. To address this problem, we developed auxiliary programs in Python to automate this process, and we plan to create an executable version of auxiliary tools for use by others. Third, since equations are inserted into notes as images in Zim, instructors may need to further adjust the resolution of images for better visualization or consider using alternative software that display equations with markdown syntax directly. Still, those limitations do not compromise the usefulness of the SMART handout in AGE teaching, and we expect it to make further contributions, not only for the GTAP model, but also for the broader community of AGE teaching and capacity building.

5. Conclusions

While recognizing the importance of AGE analysis in research and future job opportunities, students may find the process of learning how to undertake AGE analysis confusing, difficult, and sometimes frustrating. This phenomenon should not be interpreted as students' lack of interest or effort but is more likely due to the large number of materials necessary for AGE teaching, from both the current course and its prerequisites. In this paper, we propose the SMART handout as an innovative and interactive teaching tool to help students learn AGE analysis more effectively. The SMART handout facilitates learning by providing a knowledge network, illustrating relationships between concepts, and offering convenient cross-referencing of key terms. Based on its successful application in the teaching of the GTAP model, we have found that the SMART handout enhances AGE teaching and also has the potential to be generalized to other courses on general equilibrium analysis as well as other topics. Overall, the SMART handout can greatly facilitate learning AGE analysis, thereby benefiting those who are today's students, and tomorrow's researchers.

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