

Back to the Future: A 25-year Retrospective on GTAP and the Shaping of a New Agenda

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This article looks back at 25 years of achievements of the Global Trade Analysis Project (GTAP) from different angles. It covers the design features of the project and the collaboration in a global research network, the contributions GTAP has made to better informed trade policy making, its contributions in the area of environment and climate change and its capacity to absorb theoretical developments in applied modeling. The paper also makes some suggestions about future directions.

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1. Introduction

Looking back on 25 years of achievements of the Global Trade Analysis Project (GTAP) from different perspectives was the aim of the opening panel at the 20th Annual Conference on Global Economic Analysis, held at Purdue University, June 7-9, 2017. The five authors of this article introduced that session and we all responded enthusiastically to the opportunity to offer our views on GTAP. While we come from different backgrounds we have one thing in common: GTAP has played a big role in our professional lives for many years.

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The achievements of GTAP are so numerous that this article can only cover some of them, but we hope to have touched on some of the most important ones. Frank van Tongeren reflects on GTAP as a common language and a public good. He argues that the unique design features of the project have enabled GTAP to become much more than a repository of data and models. Bob Koopman discusses the contributions of GTAP to better trade policy analysis, and reminds us of the importance of the comprehensive, economy-wide view on trade reforms that is inherent in general equilibrium analysis. Stephen Karingi zooms in on the African experience, and the role of GTAP as tool for advancing trade analysis, and economic integration more widely, on the continent. John Reilly reminds us of the theoretical and practical challenges to integrating physical data into economic analysis in theoretically consistent ways to enable sound analysis of environmental and climate change issues. Finally, Joe Francois discusses the achievements that have been made to integrate developments in trade theory into applied quantitative modeling and maps an agenda for the building of further bridges between theory and practice.

Five different perspectives, but a common view: the GTAP network has continued to evolve to successfully respond to the needs for applied economic analysis in areas where a view beyond national borders is required.

2. GTAP as a common language and a public good¹

Constructing a database of global economic activity and trade, sustaining it over a long time period of time, and enabling model-based analyses that rely on that database are remarkable achievements. But a unique feature, and indeed a source of the enormous growth of the GTAP network is that it has been conceived from the outset as a public good. The strong network economies within its open architecture go hand-in hand with the evolution of GTAP as a vehicle for communication amongst like-minded: GTAP as a common language.

2.1 GTAP as a common language

A common language is obviously a prerequisite for communication. But GTAP is more: it is a vehicle that helps us understand the very complex system that is our world economy. The basic ingredients of any language consist of a vocabulary and rules to use them, its syntax and grammar. But words have no absolute meaning, they are defined by their use.²

In our case, the vocabulary is codified in a beautiful soup of variable names. GTAP model users will recognize labels such as 'qo', 'tf', 'ams', 'qfd' and so on, which only mean something when they are used in a specific analytical context.

¹Contributed by Frank van Tongeren.

²This is a very condensed summary of the complex arguments made by Ludwig Wittgenstein in his *Philosophical Investigations* (Wittgenstein, 1958).

The concept of economic welfare is another example of a term that has a very specific meaning in the context of general equilibrium analysis. It helps to understand the economic gains from policy reforms, and the clever decomposition provided with the GTAP model allows identifying the various sources of changes in overall economic welfare, such as allocative efficiency gains, endowments, technology and terms of trade. However, the meaning attached to it in general equilibrium analysis does not necessarily correspond with the understanding in every-day use.

Our syntax and grammar are laid down and governed by a mathematical structure: a solvable system of non-linear equations. This is at once convenient, as there is no need to invent a new grammar for the GTAP language, and extremely useful in using the language to understand economic problems. The mathematical formulation in a general equilibrium setting gives us a strong structure to the problem. This structure also sharpens the economist's way of thinking: there is always a trade off. In the closed general equilibrium system there is inevitably a reallocation in response to an exogenous shock. Some will gain, others will lose, but there is no way to make everyone gain unless the global production possibility frontier is expanded. GTAP forces us to avoid 'idle speculation', as I learned myself from Tom Hertel when first attending a GTAP short course in 1996.

Two elements are special to the GTAP language. First, the data which are the economic observations that we describe and try to understand with our language. The second element is a set of software tools. Those are, of course, necessary to solving the system of non-linear model equations, but more generally they are also a tool to codify and transfer insights and knowledge.

The potential for it to be written down in transferable 'books', allows each writer to share what they have done with others. The architecture and software support makes model versions transferable through straightforward manipulations. The availability to share non-standard specifications helps to advance the theory and numerical applications by enabling a much more thorough process of peer reviewing and scrutinizing than would be possible through a traditional journal review process.³

Speaking GTAP means sharing a common ground for understanding the world economy, and by interacting through our common language, we jointly enhance our understanding of it—and develop the language in the process to keep it fit for purpose. The common language thus creates a 'club' of like minded individuals, but it can exclude those that are not speaking the same language. And it render its users blind to concepts not in the language.

With its strong rooting in economic theory, the applied general equilibrium analysis (AGE) inevitably leads to the conclusion that there are aggregate gains from opening up the economy to international trade, and GTAP-based analysis

³Section 6 discusses developments in trade theory that have become applicable and more routinized through GTAP.

has made that point numerous times.⁴ Yet, there are growing concerns amongst citizens and voters in many parts of the world about side effects of globalization, of which international trade is a subset. The flip side of the reallocation of resources towards more productive uses is that some activities decline and people lose jobs. The assumption of full employment of labor in the aggregate provides little solace for those who find that their skills and competencies are not perfectly transferable across sectors and labor is not perfectly mobile, at least in the short- to medium term.⁵

But the GTAP language has shown itself to be remarkably flexible: it has expanded its domain from the initial focus on trade and agriculture to many areas of global economic analysis.⁶ Conference participants are no longer just AGE model geeks but include more and more researchers from other fields working on global economic issues. The language is evolving and the vocabulary is updated in the process. Most recently this is laid down in an updated version of the standard GTAP model (Corong et al. (2017)).

The GTAP language is spread by using it in discussions and in writing. The short course has helped over the years to initiate very many newcomers from all over the world. This is a small entry cost to enjoy the benefits network economies: the value of the GTAP language to the individual speaker increases with the number of speakers.

2.2 GTAP as a public good

Qualifying GTAP as a public good may not be quite accurate. It is perhaps better described as a club good with network economies. It has collectivity in consumption: one researcher's use of its resources does not diminish the availability to others, quite to the contrary! It is potentially excludable: people not in the network can potentially be deprived from using the resources. And, unlike national defense, one can voluntarily decide not to use the services provided.

Harnessing the power of network economies was not an obvious thing to do in the trade research community, or indeed in economic research more generally, when GTAP started 25 years ago. Individual researchers and institutions would typically guard their tools, data and recipes they used in their analysis, often resulting in wasteful duplication of efforts in data collection, model building and a lack of transparency and reproducibility of results.

At the heart of the success of the organizational model lies the recognition that

⁴Section 3 argues that it is very important to ascertain and communicate the incremental benefits from trade reform, i.e. to isolate the effects of a specific policy change.

⁵This argument naturally leads to a call for a better treatment of labor markets in the AGE framework. It also implies that trade policy making should be seen together with other areas of public policy.

⁶Section 5 discusses integrating environmental and climate change issues consistently into the AGE framework and into long-term projections.

the database has the most value but suffers from the typical financing problems that haunt the provision of public goods. The GTAP approach has succeeded in reducing the costs of doing large scale quantitative modeling for individual researchers to such an extent that the marginal benefits of joining in the effort at least equal the marginal costs. Once you have paid your entrance fee to be 'in the club', there is a strong incentive to continue contributing. This is supported by a granular structure and various types of 'entrance fees'—from the financial and intellectual efforts to provide data, to attend a short course, to database subscription all the way to annual fees to become a board member, which caters to the capacities and willingness to pay of different groups of GTAP network participants. In a Lindahl equilibrium, this differentiated structure of payments allocates the costs of providing the public good to consumers such that the individual price paid equals everyone's marginal valuation of having the good provided and the sum of payments covers the total costs.

I admit that I still struggle to fully understand the incentive structure. The motivations to contribute to the network are certainly going beyond the classical economic motives to balance marginal cost and marginal benefits in measurable ways. They also include the desire to be part of 'something' and to be valued and recognized for your contributions.

The open collaboration in the GTAP network has enormously improved the quality of the analysis and has made large scale applied economic modeling accessible for many. It has contributed to better policy choices by enabling a better informed use of data and models and has created a collective intellectual capital that is unparalleled.⁷

Thanks to its unique organizational model GTAP has been able to grow spectacularly in size and scope and it continues to be a source of innovation and inspiration for policy-relevant research. So, let us have look at the evolution of some of the topics the GTAP community has been dealing with over the years.

2.3 GTAP language at work

How has the GTAP network been addressing issues that concern citizens and voters today? Is it contributing to the debate when trade and globalization are seen as threats by many, when the state of the natural environment and natural resources call for action to safeguard the future, and when the widening of inequality in income and wealth leads to discontent in many countries?

It is extremely hard to judge the contributions that the network has made on those issues. For one, we do not have a good counter-factual to measure the impacts that conferences, research papers and personal discussion make in the public debate and on policy making. We cannot simulate a world without GTAP, but we

⁷Section 4 argues that GTAP has not only made trade policy accessible for many, but also supported policy towards economic integration within Africa and between Africa and its main trading partners. Importantly re-balancing the negotiating capacities in trade negotiations.

can look at the evolution of topics with which the network has been dealing over time.

A relatively simple textual analysis of GTAP conference abstracts between 2001-2016 illustrates the evolution of three important topics treated by the GTAP network: trade, environment and natural resources, the distributional impacts of policies. The textual analysis uses an automated tool that classifies text into a hierarchy of concepts, like a librarian.⁸ It searches through text for the occurrence of given terms (concept labels) and then maps them into a hierarchical classification system, with roots and branches like the Harmonized System of trade classification. For example Figure 1 shows a subset of the concept labels related to 'international trade' that are mapped into the hierarchy in Figure 2.



Figure 1. Concepts related to 'international trade'

The number of abstracts submitted to the Annual Conference on Global Economic Analysis has seen a steady growth over the years.⁹ Starting from 65 submissions in 2001, the number of abstracts reached 339 in 2016. Peaks occurred in 2004 (Washington DC, 379 submissions) and in 2011 (Venice, 343 submissions). Between 2012 and 2015 annual abstract submissions hovered around an average of 275, to rise again in 2016 (Washington, DC).

The algorithm that classifies the occurrence of terms identifies a rise and decline of work on international trade. With much attention to the World Trade Organization (WTO) Doha Round, more than 600 occurrences of trade-related terms are

⁸With many thanks to Ginger Batta of the GTAP Center for providing the files and to Thierry Vebr of OECD for running his textual analysis magic on 3811 conference abstracts.

⁹The first conference took place in 1998 in West Lafayette, but digitalized abstracts are available only from 2001.

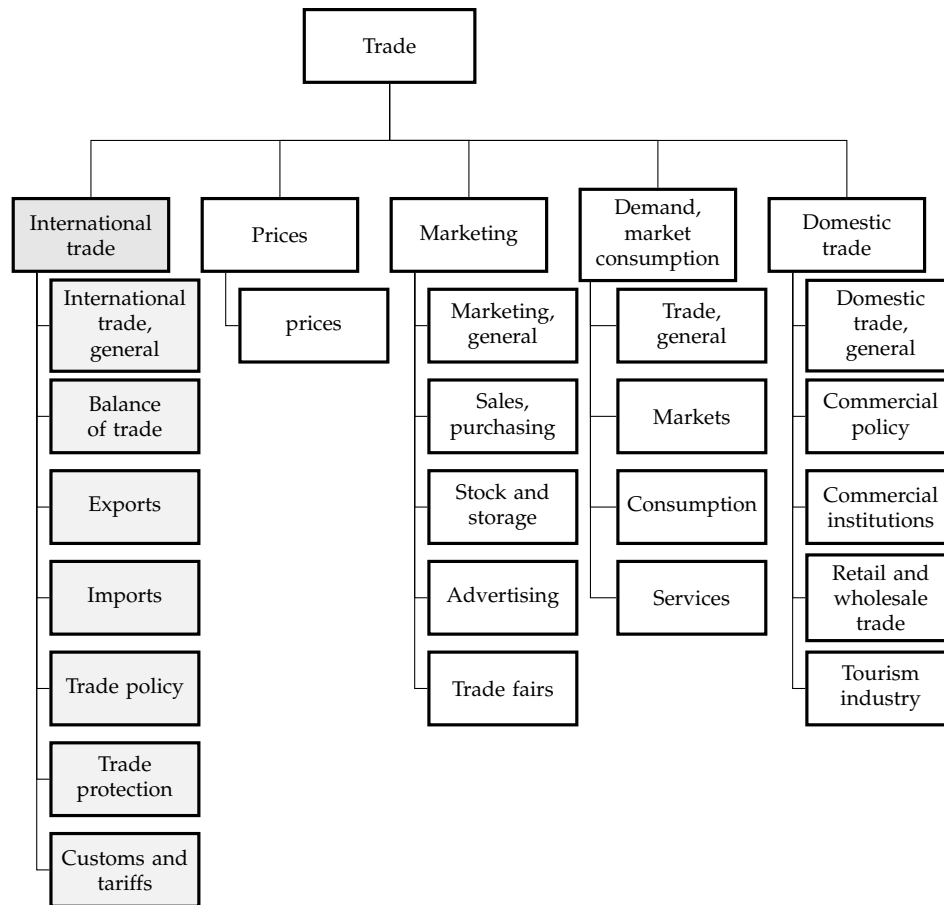


Figure 2. International trade concepts are mapped into a hierarchy of trade knowledge domains

counted in the peak year 2004 (conference theme: international trade, poverty and the environment), followed by a steady decline to just above 100 counts in the last year 2016. This seeming decline in work on trade is further discussed below.

While trade seems to have seen a steadily reduced attention from GTAP researches, environment and natural resources has been picking up, at least until 2011 with the Venice conference seeing the largest number of submissions with abstracts that contain terms pertaining to environment and natural resources (conference theme: Governing global challenges: climate change, trade, finance and development). After 2011, the count of environment-related terms in submitted abstracts registers a precipitous decline.

Attention to issues of income distribution appears to be not very explicit in the abstracts submitted, on average only 44 occurrences of words relating to distributional issues are counted. This is a bit surprising in view of the fact that one of the strengths of AGE modeling is the recognition of reallocation and re-distribution between sectors and production factors. One explanation may be that it is so evident

to modelers that it is not considered worth mentioning. Another possibility is that the classification algorithm simply does not pick up the specific GTAP vocabulary used.¹⁰

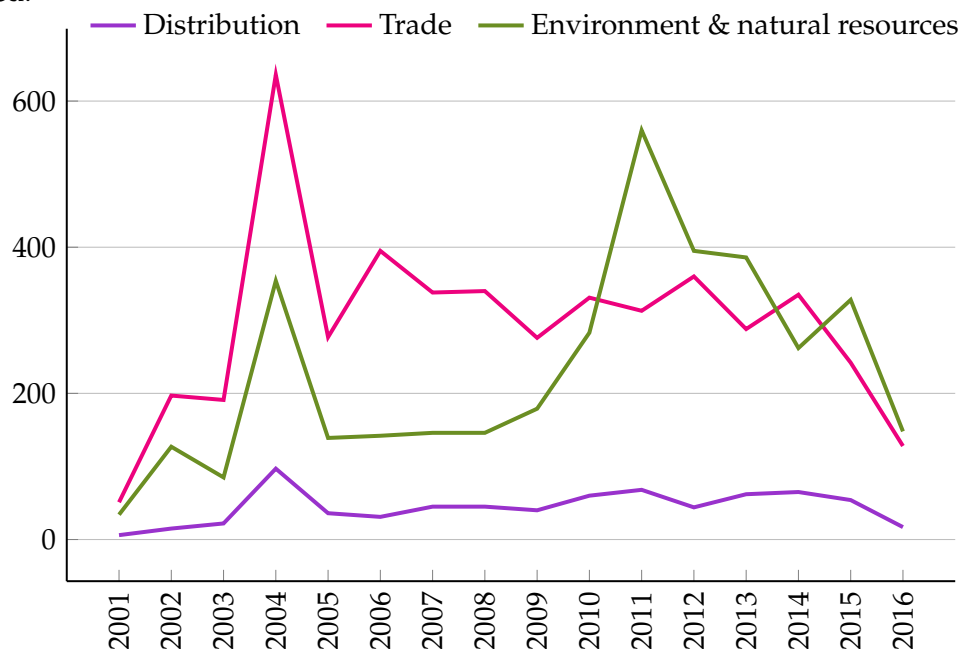


Figure 3. Evolution of topics at the Annual Conference on Global Economic Analysis

Figure 4 provides some insights on the weight of 'high-level knowledge domains' in the submitted abstracts between 2011-2016. Those high-level domains can be thought of as the main branches in a classification system. Clearly the domain 'trade' has the highest share over time. It turns out that the second most important high-level domain 'management and productivity' includes concepts such as 'value chains', 'vertical integration', 'trade in value added', 'agglomeration economies'. All those are clearly part and parcel of modern trade analysis but are not classified as such by the 'automatic librarian'. Drilling down further reveals that the apparent decline in trade topics over the years in Figure 3 is in fact explained by a shift towards those more recent concepts. Far from turning its back on analysis of international trade, the GTAP community has embraced the developments in trade theory and applied research and has expanded its vocabulary and tools accordingly.

The textual analysis discussed here is admittedly simple, just counting the occurrence of terms, or concepts. Surely, the functioning of the classification algorithm can be perfected with more fine-tuning of relevant terms and concepts. Ide-

¹⁰The algorithm was primed to search for the following concepts: income distribution, distributive effects, distribution costs, population distribution, age distribution, geographical distribution, wealth distribution, distribution, income redistribution.

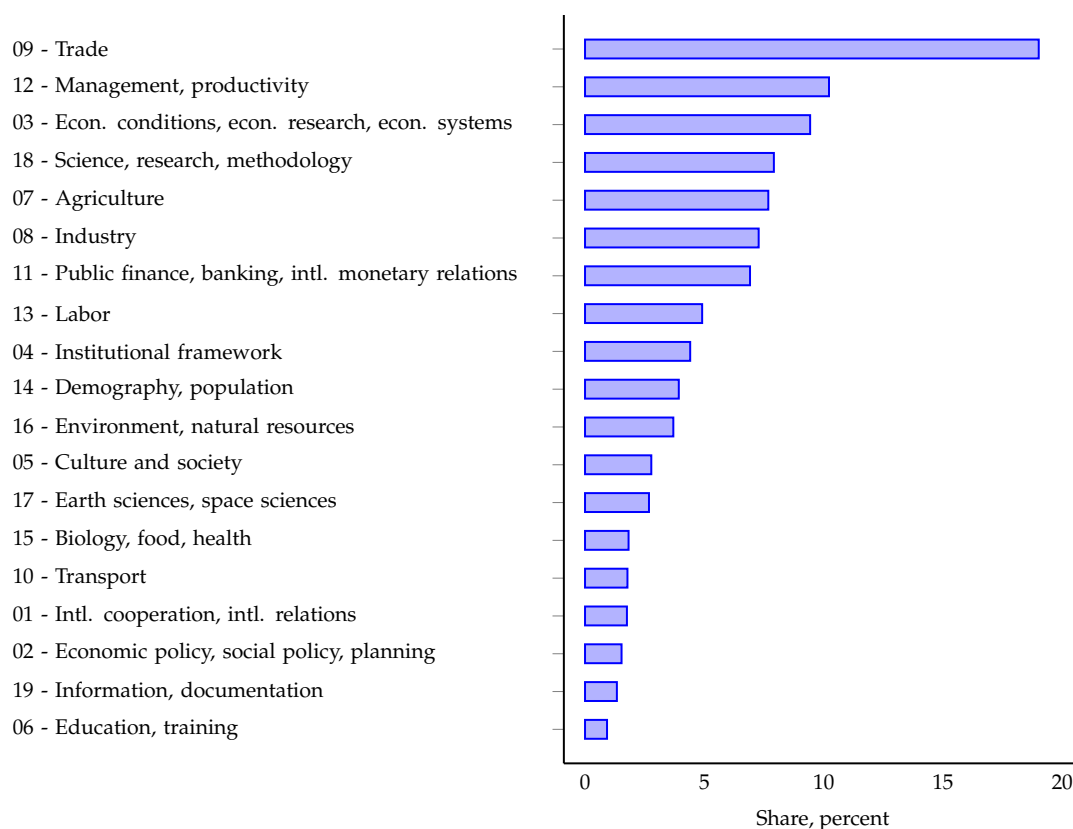


Figure 4. Breakdown of topics at the Annual Conference on Global Economic Analysis

ally one would also want to investigate how the conclusions of research in those domains have evolved over time. Have conclusions about the benefits of trade reforms changed over time, as more refined tariff data have become available, as using rich household income and expenditure data in a AGE model has become possible and as newer insights into trade by heterogeneous firms have made their way into applied modeling?

2.4 In conclusion

The unique organizational structure of GTAP has enabled its enormous success over the past 25 years. It has succeeded in providing and sustaining an (almost) public good that has transformed the way global economic analysis is performed. More than a database and a model, it has become a common language to describe and better understand global economic issues. As any language, GTAP has been dynamically evolving with its use and with its users. Indeed, it is the people who make it work!

3. GTAP as an instrument for advancing trade policy analysis¹¹

In the late 1980's through the mid 1990's it was rather exciting times to be conducting and presenting trade policy analysis on United States (US), European, and global agriculture trade. There were major multilateral negotiations ongoing within the framework of the General Agreement on Tariffs and Trade (GATT), and the US, Mexico and Canada were negotiating a deep regional agreement known as the North American Free Trade Agreement (NAFTA). At the same time the European Union (EU) was giving serious consideration to significant change in its agricultural policies and the planned economies in Europe, formerly the European breadbasket, were beginning to open up and transition to market economies and for many, eventual integration into the EU. There was heavy demand for analytical insights into these and other changes by policy makers, businesses and the general public. The nature of these changes were broad and deep, with effects across many sectors and many countries, and thus appropriate in many ways for AGE.

Early work using AGE included [Dixon et al. \(1982\)](#), [Derviş, de Melo, and Robinson \(1982\)](#), [Deardorff and Stern \(1981\)](#), [Whalley \(1975\)](#), [Whalley \(1982\)](#) and [de Melo and Tarr \(1988\)](#), among many others. Most of these early efforts used unique model coding and underlying data sets. All generated important insights on the impacts of reducing trade barriers, particularly with respect to the distribution of effects across sectors, factor markets, and in some cases countries.

These were truly extraordinary times for the conduct of trade and agricultural policy analysis. Many government and academic research institutes were recognizing the usefulness and power of large-scale simulation and econometric analysis that new software and computing capabilities provided and which allowed for detailed analysis of proposed policy changes. Among such organizations were the World Bank, the Organization for Economic Cooperation and Development (OECD), the Australian Productivity Commission, the Centre of Policy Studies (CoPS), the Economic Research Service (ERS) of the US Department of Agriculture, the US International Trade Commission (USITC), the Netherlands' Landbouwk Economisch Instituut (Agricultural Economics Institute or LEI), Central Planning Bureau (CPB) and the Centre for World Food Studies at Free University Amsterdam (SOW). Many of the policy changes involved truly demanding analytical requirements given both the depth and breadth of policy change under consideration and the requirement for policy measurement and representation—ranging from very detailed tariffs to tariff rate quotas (TRQs) to set-aside payments. While the analysis was demanding and complex the nature of the work to inform government negotiators did not necessarily lend itself to academic publications.

By the early 2000's global trade analysis increasingly focused on the numerous bilateral and regional trade agreements (RTAs) under negotiation. The number of preferential trade agreements (PTA) under negotiation soared, as epitomized by

¹¹Contributed by Robert Koopman.

the United States Trade Representative (USTR) Robert Zoellick's focus on competitive trade liberalization, as well as greater interest in the role of non-tariff measures in driving trade outcomes—partly because these new RTAs were increasingly going into new areas such as services, regulatory regimes, and investment (See [Crawford and Fiorentino \(2005\)](#)).

3.1 Demand for analysis of the wide-ranging set of issues from policy makers was extraordinary.

It was into this dynamic trade policy world that GTAP was born. GTAP aimed to reduce entry costs for researchers through a consortium arrangement that would leverage resources, capabilities, and interest with other governmental and non-governmental research organizations. At ERS Sherman Robinson was visiting and teaching a course on single country AGE models, which provided a nice complement to ERS' many partial equilibrium agricultural policy models and the rapidly growing use of gravity models in explaining trade flows, for example [Anderson \(1979\)](#) and Anderson and van Wincoop's seminal pieces ([Anderson and van Wincoop \(2003\)](#) and [Anderson and van Wincoop \(2004\)](#)). While the rapid developments in general equilibrium gravity were indeed empirically powerful in explaining trade flows these models were unable, at the time, to generate the kind of detailed ex ante analysis of trade policy changes by specific policy change or specific industry that many policy makers demanded. Thus detailed partial and general equilibrium simulation models provided the most important analytical tools to provide these insights.

Sherman Robinson, working variously with Mary Burfisher and Karen Thierfelder wrote some very thoughtful papers on NAFTA and RTA impacts, including on migration. At about the same time Marinos Tsigas was at ERS working on the GTAP model in collaboration with Tom Hertel and colleagues at the Center for Global Trade Analysis, Purdue University ([Hertel \(1997\)](#)). Mark Gehlhar ([Gehlhar \(1996\)](#), and later, [Wang, Gehlhar, and Yao \(2007\)](#)) was also at ERS working on the surprisingly challenging effort to balance global trade data, both to balance the world and to concord it to the GTAP sectors. Vernon Roningen's team at ERS developed a global partial equilibrium simulation model (SWOPSIM, see [Roningen \(1986\)](#) and [Roningen \(1991\)](#)) that was generating results on possible Uruguay Round Agreement on agricultural (URAA) reform scenarios. Other simulation models were being used to generate detailed, generally unpublished, policy analysis on the URAA, reform of the European Unions' Common Agricultural Policy and expansion of the European Union. This analysis usually fell into two categories—broader, big picture, longer run analysis to inform the broader public debate and shorter, very quick turn around, detailed policy analysis with direct communication with policy makers. The quick turn around analysis often involved faxing—these were largely pre-email days—results of policy scenarios overnight to negotiators. Such analysis was rarely made public, though summary pieces pub-

lished after a successful negotiation often drew on that material. AGE analysis was not very much used in the short turn around work. However, the GTAP effort was critical for allowing researchers to provide broad framing analysis—used to get policy makers attention as well as inform the public debate that reflected much better the most current contours of negotiations.

But it was also an increasingly controversial time for trade policy analysis. AGE and more aggregate models were often criticized for being too abstract and well, too aggregated—both in terms of sectors and policy measures (for instance [Ackerman and Gallagher \(2008\)](#)). These models were also often accused of being "black boxes", where complex theory, model structure, and data were so complicated that readers would have a hard time understanding what drove the model results. Attempts to address these criticisms were provided by [Piermartini and Teh \(2005\)](#) and [Bouët \(2006\)](#) who provided guides to understanding such models.

However, such criticisms also played an important role in improving various aspects of the GTAP model and the data. The protection data used in GTAP evolved overtime, particularly when it became clear that multilateral trade policy negotiations were based on bound tariffs while PTA were typically based on applied tariffs. Furthermore, product aggregation, tariff rate quotas, and issues such as prohibitive tariffs, were often important to measure carefully and efforts such as [Bouët et al. \(2004\)](#) at Centre d'Etudes Prospectives et d'Informations Internationales (CEPII) resulted in substantial improvements in the underlying GTAP protection database, and therefore helped improve the accuracy of the policy analysis.

In addition to improving the protection data there were efforts to enhance the capacity to break out more sectors (see [Horridge and Laborde \(2008\)](#) and [Horridge \(2005\)](#)), and innovations that allowed partial equilibrium within general equilibrium (see [Grant, Hertel, and Rutherford \(2006\)](#), [Grant, Hertel, and Rutherford \(2009\)](#) and [Narayanan, Hertel, and Horridge \(2010\)](#)) that allowed for treatment of product specific policy analysis, such as tariff rate quotas on specific cheeses. These efforts were responses of various research teams to address criticisms or perceived shortcomings in the GTAP product lines ability to provide the more detailed and realistic analysis required for applied policy work.

The evolution of the consortium's capabilities, combined with GTAP Center's continuing efforts, often working closely with consortium members, to update the GTAP database, add more countries (for example, African countries in particular)¹² and expand the dimensions of data and issues to be analyzed, for example GTAP Energy ([Burniaux and Truong, 2002](#)), Migration ([Walmsley, Winters, and Ahmed, 2007](#)), and Agricultural Ecological Zones ([Plevin et al. \(2014\)](#)), have created an exceptionally capable and flexible database and set of models that could be quickly and efficiently deployed to address important policy related questions.

For example, during the period 2000 and 2016, during the peak phase of the

¹²See GTAP resource <https://www.gtap.agecon.purdue.edu/databases/Africa/v1/default.asp>.

"Competitive Liberalization" phase, the USITC government negotiated PTA with over 17 countries. In 2004 Congressional legislation required the USITC to analyze each of the actual agreements negotiated and provide a report to Congress and the USTR within 90 days of the signing of the agreement to help inform the Congressional debate over the resulting legislation. The USITC conducted over 9 individual agreement assessments and most used GTAP based data and models as a core element in the assessments. In addition, the USITC was required to provide 3 assessments of the combined effect of all the agreements signed under the various authorizing legislations, and all 3 used the GTAP database and model. The ability to quickly analyze a specific agreement and to use a common analytical framework to assess the market access provisions of the agreements allowed the USITC to successfully meet these demanding Congressional requirements. The quantitative assessments provided were used by members of Congress to help inform their decisions on how they would vote. These reports were viewed as critical pieces to the US government's efforts to analyze, understand, and implement a consistent and coherent trade policy strategy.

The broad debate over trade and trade policy's impacts on the US economy during this period led to very heated exchanges over the appropriate analysis, and particularly the size of the various agreements effects. Many proponents of trade liberalization argued that the agreements had very big positive effects on the US economy, while opponents argued they had very big negative effects. Both sides argued that the assessments by the USITC, and others, using GTAP and GTAP like frameworks were understating the effects of the agreements, particularly the market access components. In general these arguments were based on comparing post agreement, actual changes in trade flows, output, or employment in various sectors to the reported liberalization scenarios implemented in the reports. In almost all cases changes in these variables were indeed larger than those reported in the policy scenarios. Did this mean these analyses were incorrect? In general the answer is no. The reports were not attempts to forecast or predict the future outcome of trade flows, output, and employment from all of the economic forces acting on those variables, but rather the effects due solely to trade policy changes in the agreements, particularly market access measures.

We know from ex post empirical work that one of the main determinants of trade flows between countries is relative GDP growth, the composition of GDP growth among components, exchange rates, changes in consumer tastes, and in the era of global value chains flows of foreign direct investment and changes in technology and transportation costs (see [IMF \(2016\)](#), [Timmer et al. \(2016\)](#), [Haugh et al. \(2016\)](#), and [Auboin and Borino \(2017\)](#)). When policy makers request an economic assessment of a specific trade agreement as signed between the parties, as opposed to requesting scenarios of the potential evolution of trade between countries, economists are likely to limit the analysis to the marginal effects of the agreement in a comparative static, or simplified dynamic setting. The benefit of such

analysis is that it emphasizes the marginal effects of the agreement, but the shortcoming is that the analysis then fails to illustrate other, often much larger forces, driving trade. AGE models are well designed and calibrated for the first question, but can also be usefully used for the second question, if economists are willing to attempt to address the bigger forces driving trade.

Thus critics on both sides of the debate often misunderstood the objective of the analysis for these assessments, which was to isolate the effects of the negotiated trade policy, particularly the market access commitments. One of the underappreciated aspects of models like GTAP is that it provides a well founded, conceptual limit to "magical" thinking around the effects of trade agreements. Models like GTAP help policy makers understand that at any given time there is only so much capital and labor, and that there are limits on how much more output can be generated from those factor endowments, and that growth in some sectors usually means drawing capital and labor away from other sectors. For instance analyses conducted at the USITC suggested that the net effects of the US trade agreements were small and positive, but they also showed that the sectoral effects could vary widely, and that the agreements would indeed bring about adjustments that could affect output and employment in various sectors differently. Recently it has been increasingly clear that going beyond the sectoral margins of adjustment and looking at households, labor categories, and geographic distribution of effects are important for the evolution of the political economy of trade policy changes (see for instance [Autor, Dorn, and H.Hanson \(2013\)](#) and [Dauth, Findeisen, and Suedekum \(2017\)](#)).

While capital and labor increase over time, and technological change can raise the productivity of a given amounts of capital and labor, expecting any particular PTA to affect the endowments and technological productivity of a wealthy, developed country like the US with relatively low trade barriers, that is also at the technology frontier is generally unfounded. For countries in different circumstances the static and dynamic effects of trade agreements may be more profound. Thus trade agreements can have bigger effects if trade barriers are high and a country's production technology is far from the global frontier. Trade agreements might have more influence on capital availability (through domestic and foreign investment) and labor force participation if the country was initially isolated and suffering from underutilization of its core factors of production.

But even in these cases, where the static and dynamic effects of trade are larger, the story is once again usually on structural adjustment in the economy, and how well domestic institutions and markets function in dealing with those adjustments. Many of those questions are important, but they are not currently well addressed by GTAP based analysis. A dynamic analysis might be more useful in such circumstances, but then the analysis will go well beyond any particular elements in a trade agreement and require more insights about technological change, factor markets and institutions, which are often far more important in driving economic

outcomes than particular elements of a trade agreement.

4. GTAP as a tool for advancing Africa's trade agenda¹³

4.1 Introduction

My experience with GTAP has mainly been with public policy making in Africa. It has been a privileged position in which, together with my colleagues at the United Nations Economic Commission for Africa (UNECA), we have been able to sit at the table with Senior Officials, policy makers and at times decision makers of African countries, to look at options that are informed by our application of GTAP tools. The context has always been efforts to answer the policy question, what are the options and which way should the African countries go, in their engagements with each other or with the rest of the world. In some instances, we have used GTAP to provide an African perspective on important but sensitive topics such as Illicit Financial Flows, which remains a major challenge, and one that African countries are determined to track and stop.

Throughout the years, GTAP has helped to inform policy proposals and better structure inter-governmental discussions among African countries on matters of trade arrangements, trade agreements (at bilateral, regional and global level), and particularly regional integration. The popularization, improvement and increased use of GTAP tools have allowed UNECA to undertake robust empirical analysis leading to the formulation of sound policy recommendations which have greatly resonated in the ears of African policy makers. In fact, not only were recommendations heard but they have actually influenced the design, implementation and monitoring of a number of reforms on the ground as the examples provided in this paper show.

4.2 GTAP and the African regional integration agenda

The evolution of regional integration in Africa provides an eloquent illustration of the impact of GTAP tools on policy outcomes. Regional market integration is seen as one of the most critical development pillars for Africa. Back in 1991, a clear roadmap for Africa's regional integration was developed and approved by the African Union Member States, through the Abuja Treaty, the ultimate objective of which is to create an African Economic Community by the year 2028.

Contrary to what many people might think, GTAP applications for the regional integration agenda date back to the early 2000's, if not before. In the context of Abuja Treaty, the different Regional Economic Communities, popularly known as RECs, needed to move from preferential trade areas, towards customs union, through the Free Trade Areas or Regional Trading Arrangements(FTA). The empirical analysis of how trade would be created (and diverted), and the adjustment is-

¹³Contributed by Stephen Karingi.

sues arising from the creation of the FTA, became necessary as the negotiations are first and foremost, between member States. And so, a case that comes to mind arose in 2000, when the Common Market for Eastern and Southern Africa (COMESA), issued a call for proposals, in which GTAP tools would become instrumental. The key area of focus for the call was to analyze the implications for COMESA member countries of deepening integration by going beyond being just a preferential trading area (PTA), to a FTA with reciprocal eliminations of tariff barriers and subsequently a Customs Union. The political economy significance of the success or failure of the efforts to deepen integration in COMESA for the other RECs and by extension, Africa as a whole, was not lost on development practitioners considering that COMESA had a membership of 19 African countries.

I had the privilege of leading the team from the Kenya Institute for Public Policy Research and Analysis (KIPPRA) that was awarded the opportunity to use GTAP to examine what it meant for the 19 member States of COMESA to come together and form an FTA and eventually a Customs Union ([Karingi, Siriwardana, and Ronge \(2002\)](#)). It was not a simple task. For one, many researchers and practitioners had not been exposed to the general equilibrium modeling framework in which the GTAP data was to be employed. It was a very demanding effort, but ultimately fulfilling, when the findings of the work were presented to experts from COMESA member States. The task was not made any easier by the fact that the number of African countries that were individually represented in the database at that time was quite limited. Fortunately, the GTAP database has the flexibility through which one can create realistic sub-regions, and it was possible to have a rest of COMESA grouping. I am pleased to say, though it was not an easy task, the published work of this exercise was very instrumental in convincing the COMESA member States to take the next step in their Treaty to form the FTA, and up to today we continue to make reference to the analysis of the Customs Union dimension of the work undertaken in the early 2000's. Today, 16 of the 19 COMESA member States have acceded to the FTA, and just like the GTAP applications had shown, intra-COMESA trade has grown significantly since the launch of the FTA.

While progress made by African countries and sub-regions to comply with the Abuja Treaty's key steps had been uneven, African Ministers of trade recommended in 2010 to fast-track the regional integration process. This became necessary because trade between RECs is compromised by high tariffs and other non-tariff barriers. Therefore, in 2012 at the 18th African Union Summit, in Addis Ababa, the African Heads of States and Government agreed to envisage an African Continental Free Trade Area (CFTA) with 2017 as tentative date for its establishment. In the lead-up to this decision, there were two important publications led by the UNECA under its Assessing Regional Integration in Africa (ARIA) publication series. The fourth edition of ARIA focused on enhancing intra-African trade ([Economic Commission for Africa, African Development Bank, and African Union Commission, 2010](#)). But it was in the fifth edition, whose theme was towards a continental FTA,

that GTAP tools were instrumental ([Economic Commission for Africa, African Development Bank, and African Union Commission, 2012](#)).

And thus, before the African leaders converged in Addis Ababa in January of 2012, ARIA V was published and a lot of advocacy work followed, including demonstration of the direction the trade growth in Africa would take, were they to agree moving towards a CFTA. Whereas these are admittedly ambitious reform targets, progress has been significant to date, with the CFTA negotiations officially launched in June 2015, and ongoing steady efforts to reach a framework agreement by the end of 2017.

The role of UNECA through incessant advocacy of the expected reform benefits for African countries, backed up with analytical work (relying on the use of GTAP tools) demonstrated the potential of CFTA in boosting formal intra-African trade and its industrial content. This contribution of UNECA through GTAP has been recognized as highly instrumental in the process led by the African union. In other words, it is greatly thanks to GTAP that it has become possible to facilitate level-headed discussions among Government Senior Officials and Ministers by identifying the potential gains of deeper integration, and specifically that the idea of an ambitious CFTA has been cemented (see also [Mevel and Karingi \(2013\)](#)).

We have had the same experience in the build up to the decision to move ahead with the CFTA, when I again had the privilege of doing some work on the Tripartite Free Trade Area, which brings together three of the RECs (COMESA, EAC and South African Development Community (SADC)).

It is important to note that, whereas regional integration in Africa is a broad agenda and remains unfinished business, GTAP has played an important part in framing the discussions, including in helping African decision makers to ask questions that have led to deeper cooperation on issues such as trade facilitation, cross-border infrastructure development and services, and financing of Africa's integration. The fact that it was possible to show that intra-African trade could be doubled within a decade, made the countries agree to an Action Plan for Boosting Intra-African Trade or BIAT.

4.3 GTAP, Africa and the multilateral trade negotiations

Beyond regional integration, GTAP has enabled African countries to form common positions in their engagements and negotiations with the developed and emerging economies. Many would recall that it was only after the Uruguay Round of multilateral trade negotiations that African countries realized that it was not a good deal for them. Or at least they recognized that the commitments made by some of the countries were not going to have positive outcomes in Africa's favor as previously understood, especially in agriculture. Therefore, when the discussions started on a new Round of trade negotiations, and the mandate of the Doha Round was agreed, GTAP became an indispensable tool for assessing the net benefits for the different positions.

At UNECA, we have had the privilege of working closely with the African Group in Geneva. Given the experience from the Uruguay Round, Africa was clear that this time round, they had to have a voice. Without evidence, there can be no voice in Geneva as arguments can easily be dismissed as rhetoric. It is because of the desire to make sense of the various offensive and defensive proposals that the African Group depended heavily on results from GTAP applications. I am privy to the different negotiating groups and how they tried to have the support or otherwise of the African Group, starting with the scope of the duty-free quota free market access for Least Developed Countries (LDCs), the prioritization between Non-agricultural market access (NAMA) and agriculture and within the different agriculture pillars. Take the case for the duty-free quota free market access. The African countries were clear that there were benefits to be derived, one way or the other. And so, in 2006, UNECA received an urgent but very clear question from the African group. And the question was for us to confirm whether it was true that all the benefits of a duty free quota free (DFQF) agreement would go to the larger non-African LDCs and not Africa's. Using GTAP tools, we were able to rapidly respond to the time-sensitive question. Negotiators from some of the developed countries members were not keen on the way the DFQF discussions were being framed. According to GTAP simulations of the issue, UNECA was able to rapidly respond that it was true that most of the benefits of DFQF would go to the larger LDCs, however, there were going to be net benefits for Africa as well, as shown in [Karingi, Perez, and Ben Hammouda \(2007\)](#). And as such, it was important for Africa to pursue a meaningful outcome of the DFQF negotiations.

On this example and many others, African countries were able to come up with a consensus, evidence-based position on most of the issues. I clearly recall how the many simulations on the different formulae for modalities were discussed and questions asked on how they could be implemented in the context of some of the prevailing Regional Trading Arrangements in Africa (given the mix between LDCs and non-LDCs), and the need for carve outs ([Ben Hammouda, Karingi, and Mustapha, 2007](#)). These common positions are clearly reflected in the different reports and declarations of the African Ministers of Trade meetings, starting from 2004 to at least 2015, on the question of the WTO Doha Round of trade negotiations.

The important message is that UNECA has provided through GTAP applications, concrete support to the negotiations as modalities were translated to figures and policy options ([Ben Hammouda et al., 2007](#)). The role of UNECA was to provide policy options and to shed light to the economic implications of any scenarios that were being put on the table. For the first time, African negotiators were using the same models and databases to evaluate proposals like any other leading negotiating partner, on agriculture, NAMA, sensitive versus special products, on RTAs in the context of substantially all trade, reciprocity issues and the special and differential treatment, among other negotiation issues ([Ben Hammouda et al., 2008](#)). I

would dare to say, without GTAP leveling the playing field, it would not have been possible for Africa to have the strong voice as it has in the World Trade Organization today. Unfortunately, the Doha Round negotiations have not proceeded at the expected speed—in part due to GTAP-informed revelation that Africa would gain little from the conclusion of the Round.

4.4 GTAP and Africa's economic diplomacy

Beyond regional integration and the multilateral trade negotiations, GTAP has helped in shaping the conversations between Africa and two of its major partners; the United States and the European Union. Take the case of the trade and investment discussions between Africa and the United States. It is a well-known fact that with good evidence, and using the appropriate routes for engagement, it is possible to be heard during policy formulation processes in Washington. Thus, working closely with the African Group of Ambassadors in Washington DC, and led by the Permanent Representative of the African Union to Washington, UNECA started providing inputs to the pre-African Growth and Opportunity Act (AGOA) Forums of African Ministerial Group. In order to channel emerging evidence on AGOA results and what the future post-2015 could look like, UNECA partnered with the African Group Initiative at the Brookings Institution, given the recognition that Brookings had access to hearings at Congress and was also consulted by the Executive Branch in Washington on policy issues.

Using GTAP tools, UNECA—jointly with Brookings Institution—undertook a comprehensive study (Mével et al., 2013) on the African Growth and Opportunity Act (AGOA), empirically exploring the possibilities post-2015. AGOA remains a defining characteristic of the trade and commercial relationship between the United States and Africa—under which African countries, excluding North Africa, benefit from preferential access on their exports to the U.S. market—was set to expire in 2015. While highlighting the shortcomings of AGOA, the study advocated for a seamless extension of AGOA for a period of at least 10 years and proposed specific possible improvements to the legislation. The study was widely disseminated, including during the 2013 AGOA Forum between Africa and the U.S. Subsequently, this work has been highly regarded by the U.S. Administration, and particularly by the Assistant U.S. Trade Representative, who visited UNECA on several occasions to discuss the matter. A few months ahead of the 2015 deadline, the U.S. Congress voted for an extension of AGOA until 2025 with a few enhancements, including in the area of the rules of origin as advocated for in our study.

GTAP is also at the heart of UNECA's work on the Economic Partnership Agreements (EPAs) between the European Union and countries from the African, Caribbean and Pacific regions. It was in 2004 when we had to prepare a continental study on the EPAs. GTAP was very instrumental as there was no paper or empirical research at the continental and RECs level that existed then. Yet, the EPAs had become a major issue for negotiations between the EU and Africa. In fact, it is at

this point that the UNECA made a decision to join the GTAP Consortium, so that we could have a contribution to the development of the tools. African countries were keen to know the likely implications of the EPAs and so they requested the UNECA at this critical moment to provide the empirical studies on the issue.

UNECA's role is not to tell whether or not African countries should sign EPAs or not but rather to help African countries assessing what the reforms imply for their economies. Outcomes from UNECA's multiple analysis on EPAs have informed and continue informing African countries on both the benefits as well as expected losses from the reforms, and viable policy options to mitigate them (see for example [Perez and Karingi \(2007\)](#)). While most African countries have now signed the EPAs, few have actually ratified them. There are still areas of contentions for which UNECA has provided recommendations to overcome the issues and it is up to Member States to decide how to go about them. An important point worth highlighting is that in 2004 when UNECA did the first simulations with GTAP tools; some clear messages came out of the analysis. At that time, it was not clear how the EPAs would actually be implemented and so several assumptions had to be made; and the baseline scenario had to be constructed in a manner that it reflected some of the policy decisions that were under implementation. Ten years since these first studies, and now having clear knowledge of the contents of the EPAs, the credibility of the GTAP database and tools are not in question. The broad messages from 2004, have consistently remained the same, including when there was certainty in the content of the EPAs. Several RECs, including the Economic Community of West African States (ECOWAS) and EAC, did ask UNECA to assess the final EPAs, and the conclusions in 2015 and beyond confirmed the broad results of the first studies.

The third example on how GTAP has been instrumental in Africa's diplomacy is how the GTAP tools were instrumental in supporting President Thabo Mbeki's led High Level Panel on Illicit Financial Flows, which was established in 2012. The primary mandate of the Panel was to explore and gain a comprehensive understanding of the character of illicit financial flows from Africa. It was important that the Panel came up with an evidence-based report whose conclusions could stand up to rigorous scrutiny. This mattered because President Mbeki and his Panel of Eminent Personalities from within and outside Africa were to engage both African Presidents and Senior Officials from Western Capitals, including Washington DC, to get a broad consensus on the Panel's recommendations on how to deal with the illicit financial flows. It was therefore imperative that in all these consultations towards getting consensus on the way forward, that the recommendations were informed by sound empirical work. The GTAP database proved to be very useful in supporting the Panel's work. Out of this work, a Consortium for Stemming Illicit Financial Flows from Africa has been put in place. The potential for positive results out of this consortium in financing Africa's development going forward is invaluable (see [Mevel, 'Ofa, and Karingi \(2014\)](#)).

4.5 Looking to the future, and the potential roles of GTAP tools

From the foregoing examples, the importance of GTAP in informing and influencing policy decision in Africa for the past few decades is obvious. But in a rapidly evolving world, GTAP is expected to continue playing a critical role in the years to come.

For instance, as the UK has voted to leave the European Union (EU), UNECA—working closely with the Overseas Development Institute (ODI)—is actively contributing to the constructive thinking aimed at facilitating the development of a new UK-Africa trade and investment partnership. This will involve analytical work based on GTAP tools. Likewise, the emergence of mega-regional trade agreements and increasingly prominence of emerging economies in world trade forces Africa to quickly reposition itself to avoid remaining marginalized. UNECA is currently exploring the issues through empirical research using GTAP.

It is clear that GTAP is well rooted in Africa. Two out of the 20 Annual Conferences on Global Economic Analysis held to date have been organized in Africa, namely Addis Ababa (2006) and Dakar (2014); each time with UNECA playing an active role and sponsoring participants from the region to attend and disseminate their research. Capacity building activities targeted at researchers and policy makers on trade policy analysis and the utilization of modeling tools, including from GTAP, have been multiplied throughout the continent (thanks to UNECA but also particularly the International Food Policy Research Institute (IFPRI) and the WTO, among others). Such activities are even expected to be scaled up in the near future. Without doubt, policy making in Africa has benefited and will continue benefiting significantly from GTAP. Today, African experts go into negotiations, and push diplomatic efforts with well-developed positions that no longer depend on externally sourced simulations. For all of these reasons, the GTAP community can count on UNECA's support looking forward.

5. The role of GTAP in meeting the needs for quantitative environmental assessment¹⁴

Traditional applied general equilibrium modeling is able to utilize standard data from national income and product accounts and input-output tables where quantities of inputs and outputs are recorded in terms of expenditure in dollars (or other currency measures). This takes advantage of the basic conclusion of standard neo-classical economic theory that price (P) is equal to the Marginal Value Product (MVP) or Marginal Revenue Product (MRP) of the good as it is used as a production input or in final consumption. This theoretical conclusion justifies, at the margin, adding "apples and oranges" based on expenditures on them, or revenue generated from selling them, because one dollar's worth of each fruit generates one

¹⁴Contributed by John Reilly.

dollar of value. For economists, representing quantities as dollars of expenditure is thus preferred to adding up tons of fruit.¹⁵

Once we move to environmental analysis, externalities take center stage and, by definition, these external effects lead the marginal social value of the use of the product to differ from the valuation observed in the market (and recorded in national accounts). To be concrete, at the margin, a dollar expenditure on coal, a dollar expenditure on gas, and a dollar expenditure on oil can be added together as an expenditure of three dollars of energy, and that makes more economic sense than adding together tons (or energy content) of these very different fuels.¹⁶ However, if one sector's energy expenditure is primarily on coal, and another primarily on natural gas, pollutant emissions from a dollar of energy expenditure in these two sectors will be very different. For carbon dioxide emissions, for example, there is a pretty clean relationship between tons of emissions and physical quantity of the fuel that is combusted. For bituminous coal, the Energy Information Administration¹⁷ provides a value of about 98 kg per gigajoule, while for gas it is about 56 kg per gigajoule.¹⁸ Prices paid for these fuels vary across the world, and so even if one disaggregated expenditure by fuel, one still needs to be able to convert that expenditure to a physical quantity of the fuel.

GTAP, in work dating back to 1999 and debuting in the GTAP 4 Data Base, used International Energy Agency (IEA) data to provide supplemental physical accounts for fuel use (Malcolm, 1998). This allows researchers to relate fuel use to Carbon Dioxide (CO₂) and other energy-related pollution emissions. This initial effort was subsequently updated and improved (Burniaux and Truong (2002) and McDougall (2003)). In principle, this is a relatively straightforward exercise, but having this as part of the GTAP data means each researcher who might want to estimate CO₂ emissions in a GTAP simulation does not need to go back and create their own set of supplemental physical estimates of fuel use. And, while straightforward, in principle, there are any number of practical issues that arise. Among the more important of these issues, is getting separate data on energy prices (and taxes and subsidies) and then reconciling these with national input-output tables. Here GTAP put greatest weight on the IEA physical data, adjusting the economic data as needed (Burniaux, McDougall, and Truong, 2002), because of the interest in the physical accounting of CO₂ as well as the recognition that I-O tables are updated infrequently while energy prices are subject to significant swings. The separate identification of fuel taxes and fuel prices has proven an important second-best

¹⁵ Greater disaggregation can lead to more homogeneous commodity classes but even in moving to seemingly homogeneous categories such as wheat, coal, or apples there are multiple varieties and quality differences.

¹⁶ Of course, adding together the observed marginal values to get expenditure on energy does not necessarily mean one can substitute these products easily for one another.

¹⁷ https://www.eia.gov/environment/emissions/co2_vol_mass.php

¹⁸ Converted from lbs/million BTUs.

consideration in climate policy design (e.g. Babiker, Reilly, and Viguier (2004) and Paltsev et al. (2007)).

CO₂ emitted from fuel use is an obvious advantage of these supplemental physical accounts. Since many other pollutants are associated with fuel combustion, it is possible to further extend pollution accounting related to fuel use to emissions such as black carbon, organic carbon, volatile organic compounds, nitrogen compounds, and sulfur emissions (e.g. Mayer et al. (2000) and Waugh et al. (2011)). In a related exercise, GTAP extended its emissions accounting to non-CO₂ greenhouse gases based on US Environmental Protection data (Rose and Lee, 2008). These emissions present more complexities than CO₂ from fossil fuels as they come from multiple sources with varying emission rates per unit of activity. While some of emissions sources are related to energy (e.g. methane from coal, gas, and oil production and gas distribution) or nitrous oxide from fuel combustion, others have non-energy sources. These include methane from rice and ruminant animal production and from municipal waste, nitrous oxide from fertilizer use, and CO₂ from cement production and land-use changes. Ideally, one would include physical quantities of the products directly related to these emissions. In practice, the emissions of a ton of nitrogen fertilizer or ruminant livestock production are not necessarily constant across different practices or environmental conditions. The conversion from expenditure to tons of physical product to emissions of the pollutant, where the emissions per ton is not constant, can be simplified. This is done by creating implied coefficients per unit of expenditure based on inventories of emissions that can be related to specific production inputs as the conversion to tons of product is not directly a guide to emissions.

Modeling of emission abatement is also more complex. Reduction of CO₂ emissions for the most part involves using less of CO₂-intensive fossil fuels, and so substitution among fuels or between energy and other inputs, relying on extensive literature estimating these elasticities, can capture CO₂ abatement and abatement costs. For non-CO₂ GHGs there are various ways to reduce emissions without abandoning the activity responsible for producing them. Methane from manure management, waste, or energy production can be captured and flared or used as energy; different forms and application methods of nitrogen fertilizer can be used to reduce nitrous oxide emissions, requiring a different modeling approach (e.g. Hyman et al. (2003)). A variety of efforts to model these reductions were the subject of Energy Modeling Forum 21 (Weyant, de la Chesnaye, and Blanford, 2006).

A challenge of modeling greenhouse gas emissions and control costs is the need for very long-term scenarios, where we anticipate new advanced technologies to appear or are concerned about how depletion of reserves of fuels may affect their cost. The physical supplemental accounts GTAP has developed have also proved useful in augmenting the standard economic data-base with physical estimates of remaining fuel resources and with engineering estimates of advanced technologies. Knowing the physical use of oil, gas, or coal over time in a dynamic model, allows

one to deplete resources based on the physical use. Often a key data component of engineering estimates for advanced technologies are efficiency of conversion—how much of a fuel input is used, and how much electricity is produced. With physical accounts on 'fuel in and electricity out', per dollar of input and output, one can specify advanced technologies as substitutes for existing sectors in the GTAP data base in a manner consistent with both economics and the engineering conversion data—and hence keep emissions accounting straight (McFarland, Reilly, and Herzog, 2004).

Another important set of supplemental accounts is related to land use. Highly productive land will have a high value while land with little current use, or that has not had much investment in improving it, will have low or no current value. In a set of base year traditional national income and product accounts, a simple dollar value of land is the ultimate aggregation of "apples and oranges," and in this case near continuously varying gradations of "fruit" quality. Yet land with low or no commercial value may have large carbon stocks or important ecological value not reflected in the market data. GTAP has provided supplemental physical accounts for land, marrying together data on areas of cropland (Ramankutty and Foley (1999) and Monfreda, Ramankutty, and Foley (2008)) and forest land (Sohnngen and Tennity (2004) and Sohnngen et al. (2008)) as described in Lee et al. (2005) and Avetisyan, Baldos, and Hertel (2011). A volume edited by Hertel, Rose, and Tol (2009) puts all of this together in one place: data and different models. The GTAP land data was then further integrated with the Food and Agriculture Organization (FAO) Agro-Ecological Zone (AEZ) data that help identify climatic aspects that give rise to innate differences in land quality, and presumably land value (Lee, 2005). An important policy issue related to this quantification of physical land use has been CO₂ emissions associated with bioenergy expansion. The GTAP modeling group has been a leader in supporting policy development in this area—serving as the data base construction and modeling effort that quantified indirect emissions related to bioenergy expansion that has been a basis for regulation by the California Air Resources Board (CARB) (e.g. Taheripour et al. (2010), Hertel et al. (2010), Tyner et al. (2010), Taheripour and Tyner (2013)).

Just how to represent land transformation in the applied general equilibrium framework in a way that facilitates transformation of land from one use to another, while maintaining the physical accounting, also has been a subject of concern as discussed in Gurgel et al. (2016). A simple technique applied in many studies is the constant elasticity of transformation (CET) production function that creates a substitution elasticity allowing transformation of one type of land to another. The CET production function, a sibling of the constant elasticity of substitution (CES) production function, has nice properties as it gives a gradual transformation response as relative prices of different land types change. Such a gradual supply response may reflect underlying continuous gradation of land suitability for specific uses. However, this formulation can be restrictive—generating an empirical

foundation for substitution of transformation elasticities is a challenge, and ultimately this formulation that is inconsistent with the physical accounting since a dollar unit of land transformed from one use to another through a CET does not preserve the area. The other approach is specific investment in land to transform it from one type to another. The underlying "theory" motivating this approach is that land of different types is "produced" via investment—i.e. land clearing, fencing, irrigation, fertilization, etc. Strictly applied this approach provides no limits on the ability to transform land from one type to another, suggesting that climatic factors are irrelevant. However, various constraints can be embedded to limit the area that can be transformed from one use to another based on exogenous assessments of conversion potential (e.g. [Winchester and Reilly \(2015\)](#)), or represented as an increasing supply function via land conversion specific input that is only imperfectly substitutable for the land input itself ([Gurgel et al., 2011](#)).

A basic challenge is the description of discrete land types or classes given a continuous variation in land quality, and characterizing the value and productivity of "unused" land. [Gurgel, Reilly, and Paltsev \(2007\)](#) valued all land at some level whether used or "unused" assuming that, for example, the value of virgin forest land in remote areas could be separated into a value of the existing stock of lumber, and the value of the land in terms of discounted future forest regrowth. Some efforts have also attempted to estimate recreational value of land by supplementing the data with US Forest Service data on hunting, fishing, and wildlife viewing information and parkland management costs ([Antoine, Gurgel, and Reilly, 2008](#)). The study used a benefits transfer approach to parameterize the recreation value of forestland in other regions of world, scaling the value by overall recreation expenditures in different regions to reflect implicitly differential valuation with income variation across regions. This approach raises a number of questions—does public protection of land "respond" through some governmental process to protect more land as societies value of it rises? Are these values captured by private landholder decisions? How unrealistic is it to apply a uniform recreation "use value" to all forestland in a large country? And, how important are non-use or option value of land in terms of protection? As already noted, the CET approach can be motivated by an underlying increasing cost of conversion from one type of land to another as one moves to land that is less suitable for that purpose, however, then physical accounting falls by the wayside. This issue has gotten considerable recent attention, with various proposed solutions ([Giesecke et al. \(2013\)](#), [Fujimori et al. \(2014\)](#), [Wise et al. \(2014\)](#); [van der Mensbrugghe and Peters \(2016\)](#)).

A related issue that has arisen is: What is the productivity of land converted to cropland? This arose as an issue in estimating the indirect land use emissions from bioenergy expansion as discussed in [Taheripour et al. \(2012\)](#). An initial assumption relied on what would appear to be sound economic reasoning: The land most suitable for cropland (highest potential yield) would have been converted to cropland first. By that reasoning, more recent additions would have a lower suitability, and

at the margin the yield of new cropland would be lower than the average of existing cropland. This assumption implied that to get a given amount of bioenergy required more land, and potentially more emissions from conversion of land, than if new cropland had the same productivity as existing cropland. In subsequent work, the authors assessed this assumption by running a highly resolved terrestrial ecosystem model that estimated the innate productivity of land in terms of net primary biomass productivity. Those results did not always confirm the assumption that currently unused land in a particular region and AEZ had less innate productivity than existing cropland. Potential reasons may include limits on the ecosystem modeling: estimates of innate productivity may not be directly relevant to productivity of the land for specific crops or the underlying characterization of the land may not be well-resolved to show yield variations. The assumption of highly optimized evaluation of parcels for conversion may be flawed: information to "optimize" land conversion may not exist, or other factors such as road access or nearness to processing facilities may be more important—there is a rational economic explanation but it is unrelated to yield. Or finally: Innate characteristics of the land may have relatively little to do with its productivity as cropland, especially after controlling for climate as captured in AEZs—rather it is mostly determined by investments in the land such as clearing, tiling, irrigating, access, etc.

While spatial data were at the foundation of the early GTAP land use and cover data, spatially explicit data and modeling are often crucial to environmental issues. New work at GTAP has taken on this issue again, to update, revise, and make available spatial data (Baldos, 2017). The next step in this process is to formally bring together more detailed spatial data and models linked to the AGE framework, and GTAP data. An effort that formally links a GTAP-based AGE model to a spatially explicit model of land productivity is that of Melillo et al. (2009) and Reilly et al. (2012). The GTAP group has picked up this challenge with their significant initiative to develop better spatial data (Baldos, 2017). These developments in representing land as both physical and economic variable illustrate the GTAP approach at its best. Knowing the complexity of the land issue in terms of the relationships of value, physical quantity, and productivity could well put off most research groups, or lead to development of a project so costly and time consuming that it would never be funded. However, an important GTAP principle is to not let the perfect be the enemy of the good, and instead focus on making a step in a direction that leads to greater understanding. By developing some initial data, various researchers have access to something with which different assumptions can be tested, and to which ancillary data can be added.

Turning back to energy issues, a recent, but important contribution has been to disaggregate the electricity sector in the newly released GTAP9-POWER data set (Peters, 2016). One of the critical limits for environmental analysis of existing income and product data is characterization of the electricity production as a single sector, utilizing multiple fuel inputs (and labor, capital and other intermediates).

The technical reality is that the electricity sector is composed of very different generation types—coal plants, nuclear plants, hydro facilities, gas power plants, etc. In the long run a strong case can be made that for base generation, at least for dispatchable sources of electricity, the various technologies are perfect substitutes—electricity from a nuclear power plant is no different than that from coal power plant. However, without identifying these as separate production technologies (or sectors), it is impossible to capture the long run response through a simple CES characterization among these various inputs. They are better characterized as discrete technologies with different costs and a variety of explicit dynamics that appear to limit substitutability in the short run. The [Peters \(2016\)](#) effort to augment the GTAP Database to provide separate production sectors for each electricity type provides a ready platform for many researchers to better represent the sector and test various ways of modeling it.

Another important natural resource issue is the role of water in the economy, especially for irrigation. This is an area that still needs considerable work. Early stabs at using the GTAP data and framework for analyzing the importance of water include [Calzadilla, Rehdanz, and Tol \(2010\)](#). More recently the GTAP group has included more direct links to disaggregated land and water by river basin and added separate production functions for irrigated and rainfed crops ([Taheripour, Hertel, and Liu \(2013a\)](#), [Taheripour, Hertel, and Liu \(2013b\)](#), and [Liu et al. \(2014\)](#)). Some recent work has attempted to create "irrigable land supply functions to augment the AGE framework, utilizing more resolved data from a global water resource model ([Winchester et al. \(2016\)](#) and [Ledvina et al. \(2017\)](#)). But there remain issues of how to represent readily competing uses of water within the economic model. Because water is often provided through some public investment, market pricing does not reflect the full cost and scarcity value. Possibilities to provide more water (through expansion of reservoirs or improvements in efficiency of water use or conveyance) are not well described. [Winchester et al. \(2016\)](#) and [Ledvina et al. \(2017\)](#) incorporate these indirectly in the irrigable land supply functions, but then there is no direct economic trade off in the economic model. Moving from data to modeling, the multiple uses and timing of water supply over the year, and the public provision and pricing provide a set of challenges. Incorporating these explicitly in the AGE model and data or indirectly through linkages with a detailed model of water resource supply and allocation are two possible directions.

Another area that has received attention recently is examination of land use change at the intensive margin (e.g., double cropping) instead of just at the extensive margin. Most prior GTAP work has assumed that all changes in harvested area occur at the extensive margin. However, [Taheripour, Cui, and Tyner \(2018\)](#) and [Taheripour, Zhao, and Tyner \(2017\)](#) use a historical time series of changes in crop cover and harvested area by region and found that there are significant differences among regions in the extent to which harvested area changes occur at the extensive versus the intensive margin. To the extent that changes have been to a

significant extent at the intensive margin, prior estimates of land use change and associated land use change emissions have been overstated. These authors used the historical FAO data to calibrate a new parameter that expresses the degree that land use change by region is likely to occur at the intensive or extensive margins.

The future of GTAP in terms of improving data and modeling of environmental issues within the AGE framework lies in representing the spatial variation in key economic inputs such as land and water (as moderated by climate). To make improvements will require linking the GTAP data (or GTAP based models) to spatial data and spatially resolved models. GTAP is well on its way in terms of exploring these challenges as called out by [Hertel et al. \(2017\)](#) where they propose a simple economic model solved at each spatial grid in such a way that it can be aggregated up. The development of spatial data sets is a relatively recent phenomenon and analysts generally would like to see better data with great resolution of multiple environmental attributes. It is important that, as these data sets are developed by others, we (the GTAP community) simultaneously investigate how they can be used within the AGE framework. We can then provide feedback on what features of the data sets would be most useful for our purposes, while there is still possibility to include such features in data development plans. This is an exciting next step for this modeling-making it more relevant to managing the world's natural resource base.

6. The Role of GTAP in Bridging Theory and Practice¹⁹

The GTAP project, and especially the database, has been important since its early years in the process of bringing developments in economic theory, and related developments in estimation methods, to bear for addressing a range of major policy questions. The contributions include the importance of market structure, dynamic processes, and non-tariff barriers when assessing trade policy. They also include recent advances and applications in multi-region input-output analysis. More recently, we have seen a convergence in the long-running literature on parameter estimation for AGE models, on the one hand, and recent structural estimation models (structural gravity), wherein we effectively have an integration of econometric methods with structural general equilibrium methods. In what follows, I provide a brief overview of the role GTAP has played in these areas.

6.1 Market structure

In the policy debate that surrounded the ratification of NAFTA, large-scale AGE models featured prominently in the estimation of effects. The models on offer included the Michigan model with monopolistic competition ([Brown, 1994](#)), the Cox-Harris model with both monopoly pricing and Eastman-Stykolt pricing ([Cox, 1994](#)), and a range of other applications with a mix of Armington and large group

¹⁹Contributed by Joseph Francois.

monopolistic competition specifications (USITC (1992) and Francois and Shiells (1994)). These models generally featured bespoke datasets. Reference years were different, sources for input-output tables were different, and mappings between trade statistics and industrial sector definitions were different. As a result, where different assessments provided different substantive results, it was as likely to be that these differences were due to data as they were to model structure.

Almost immediately after the NAFTA ratification debate, the ratification of the Uruguay Round marked a transition in model comparability. While many models still relied on bespoke datasets, we begin to see AGE models with the same data—the GTAP database (Hertel et al. (1995), Francois, McDonald, and Nordström (1995), Harrison, Rutherford, and Tarr (1995)). We also begin to see model comparisons across market structure assumptions, while using the same database—again the GTAP database (Francois, McDonald, and Nordström, 1996). Since this time, the GTAP database has emerged as the common standard starting point on the data front. The resulting combined efforts by institutional stakeholders through the GTAP consortium has led to continued improvements in this area. In addition, the "shared code" approach and related GTAP technical papers have also made model comparison easier, while helping focusing research on how to implement market structure in AGE models.

6.2 Dynamics

Another area where the GTAP consortium has played a useful role is in dynamic analysis. This ranges from early GTAP-based assessment of long-run impacts of trade agreements—aka comparative steady state analysis (e.g. Baldwin et al. (1997) and Francois and McDonald (1996)) to projection based climate models that integrate GTAP data into forward projected models of production and emission pathways (Golub (2013) and Sokolov et al. (2009)). Here, the combination of shared GTAP data and shared model code and satellite accounts has been critical in bridging from theory to applied analysis of forward-looking climate policies.

6.3 Multi-Region Input-Output Analysis

For anyone who has worked with the GEMPACK data utilities, the photograph and linked biography to Leontief is just one of those things that pops up on the screen from time to time. Interestingly, the GTAP project, and the more recent World Input-Output Database (WIOD) project and the joint OECD-WTO Trade in Value-Added (TiVA) initiative, have fed a revival of Leontief-type analysis, but on a global scale. In particular, with the realization that the global economy has been greatly reshaped with the emergence of regional and global production networks, the GTAP data has again lowered the entry cost for a new area of applied research, where updated methods meet new data sources Leontief could only have dreamt of. The result ranges from input-output analysis of value added trade and embodied services content in trade, to a better understanding of how cross-border pro-

duction linkages complicate design of policy targeting carbon emissions. (See for example [Johnson and Noguera \(2012\)](#), [Francois, Manchin, and Tomberger \(2015\)](#), [Koopman, Wang, and Wei \(2014\)](#), [Andrew and Peters \(2013\)](#), [Andrew, Peters, and Lennox \(2009\)](#) and [Fernández-Amador et al. \(2017\)](#)).

6.4 Policy and Trade Costs in General Equilibrium

The GTAP initiative has also made valuable contributions to the analysis of trade policy, in terms of both data and method. For example, as the theory of Non-tariff measures (NTMs) has expanded from simple instruments like quotas (see [Elbehri and Pearson \(2005\)](#)), we then moved on to modeling the iceberg or dead-weight aspects of trade costs in the GTAP framework ([Francois \(1999\)](#), [Francois \(2001\)](#) and [Hertel, Walmsley, and Itakura \(2001\)](#)). Indeed, it is now standard to include iceberg type costs in GTAP-based trade policy studies ([Hertel, 2013](#)). Most recently, "applied theory" work with the GTAP database has also been focused on fixed cost aspects or trade costs, as a factor in limiting entry of firms into foreign markets. Much of this ongoing work is centered on the Melitz framework. (See e.g. [Balistreri, Hillberry, and Rutherford \(2011\)](#), [Zhai \(2008\)](#) and [Akgul, Villoria, and Hertel \(2016\)](#)). Much like the quota and iceberg tools now standard to GTAP, we can expect future practical application of trade costs as determinants of entry as options within the GTAP framework. This offers yet another case where GTAP provides a dissemination bridge from theory to application.

6.5 Structural General Equilibrium

While there is a long-standing literature on the sources of parameters for AGE models ([Hertel et al. \(2007\)](#), [Beckman, Hertel, and Tyner \(2011\)](#); [Liu, Arndt, and Hertel \(2004\)](#)), we have recently seen rapid development in models that merge the CES-type trade bilateral estimating frameworks of gravity models with the underlying general equilibrium theory in which these trade equations are embedded. The result is a structural, general equilibrium approach to model estimation and validation ([Head and Mayer, 2014](#)). Looking forward, the GTAP project again offers a unique opportunity to bridge from this active area of research to application. We now have an internally consistent global panel dataset of Multi-regional input-output (MRIO) tables (the GTAP data vintages) with linked satellite accounts, and a network that offers ease of replication. Here, we should expect yet more substantial contributions where GTAP offers a bridge from theory to practice.

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