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Photo: Women working in the field, India.
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Considerations for gender-responsive mathematical modeling of agriculture and natural resource management

Technical report

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IN PARTNERSHIP WITH:

Introduction

Models can play a key role towards improving understanding about critical environmental and development challenges, such as declines in soil fertility due to inadequate management practices, or drops in returns to labor as soil fertility declines. They serve as logical constructs that offer a simplified representation of complex systems to provide insights into a 'perceived reality' (McCarl 1984), or a specific part of their inner workings (Gershenfeld 1998). In particular, mathematical models focus on the effects of different components of the 'target system,' and describe or predict behaviors using mathematical concepts, theories, and language (ibid 1998). In the fields of agriculture and natural resource management (NRM), decision-making models, land use planning models, statistical relationship-based or process-based models may be used to analyze biophysical and/or socioeconomic phenomena.

The purpose of this brief is to identify considerations for integrating gender and social inclusion considerations in mathematical modeling focused on agriculture and natural resource management. The brief is not a guideline per se, nor is it exhaustive in terms of entry points for gender integration in mathematical modeling. Rather, it is intended to stimulate thinking on ways to engage with gender relations to develop models that can support analysis on innovations that promote equitable and sustainable agriculture and natural resource management.

There are many different ways to design and use models depending on the type of phenomenon to be analyzed and type of questions the model needs to answer. Econometric models can and often do include gender considerations or 'gender' as an explanatory variable. In contrast, models that describe only biophysical processes will not include gender per se in the model, but may nonetheless carry gender implications that require consideration (i.e. treating gender relations as an exogenous variable that shapes the biophysical world or that influences the impacts of biophysical change). Integrating gender considerations into models requires analyses that acknowledge the complex, shifting and context-specific nature of gender roles and relations (Doss et al. 2001, Gladwin et al. 2002). Drawing on the scarce literature on gender in modeling, we demonstrate below that gender relations require consideration across key phases of the modeling cycle, including when: 1) conceptualizing the model/framework; 2) collecting data to populate the model; and 3) interpreting model outputs.

1. Conceptualizing the model/framework

Models are informed by and reflect a conceptual framework. They (often implicitly) embed assumptions about inter-agent interactions and institutions (Swallow and Swallow 2015). **Gender analysis**, which can be supported by and/or conducted with a scientist with gender expertise, is needed to underpin socio-economic or bio-economic models so as to include relevant elements in the model. As gender relations are contextually-specific, models will need to consider their particularities in the settings of interest (Fontana 2015). Moreover, depending on the scale at which a model is pegged and its substantive focus, certain gender issues may be more relevant than others.

A first important concept for gender-responsive models of household-scale processes is that of **gender-differentiation within the household**, which commonly involves an unequal distribution of costs and benefits and of decision-making power among members (Udry 1996, Doss et al. 2001, Gladwin et al. 2002, Mudhara et al. 2002). As Sen (1990) demonstrates, the household is a site of coinciding and competing interests among members, wherein women and men engage in distinct, but also shared and overlapping processes in production, as well as consumption, and decision-making.[1] Moreover, gender interacts with other social identities (age, marital status, ethnicity and so forth) to create diverse social positions within the household, which shape intra-household power relations (see Box 1). For example, a mother-in-law may have more decision-making power than a daughter-in-law; and a young man may have less authority within the household than his father. Given this intra-household differentiation, models should not assume equal opportunities or outcomes for different household members.

Gender-responsive modeling may involve integrating variables in the model that account for an **unequal access to and control over resources and assets among different groups of women and men.** As Fontana (2015, p. 1) reports in her guidelines to integrate gender in bio-economic research, "looking at issues of environmental, economic and social sustainability through a gender lens means being aware that women and men have a different capacity to access, control and use assets and resources, and that women tend to face disadvantage more than men in a number of domains." Women and men also frequently have different capacities to access information, due to unequal access to formal education, social networks, and extension services (Doss and Morris 2001, Ragasa et al. 2013). Hence, in a study on adoption of improved fallows to enhance soil fertility in Eastern Zambia, Keil et al. (2005, p. 234) account for "differences in land and labor endowments as well as wealth status found between male and female headed households." Their model shows that these differences in the availability of land and labor among women and men account for women's relatively lower adoption rates.

Another key gender issue for models focused on agriculture and natural resource management are the **labor (or time) constraints rural women typically experience given their heavy work burdens.** These are due to women's responsibilities in what are commonly called 'productive' activities (which generate income – e.g. agriculture, trade) and 'reproductive' activities (unpaid activities, which maintain the household – such as domestic tasks, collecting water and firewood, caring for children, elders, and ill household members, etc.), as well as in women's more limited ability to mobilize other people's labor compared to men (Grassi et al. 2015). Differences in labor availability among men and women farmers, when relevant, need to be accounted for to avoid the generation of 'biased' outputs. For example, Gladwin et al.'s (2002) intra- and inter-household decision-making model shows that a lack of access to land and labor prevented women from adopting a range of agroforestry innovations in Eastern Zambia.

Gender differences in access to assets and resources and the gender division of labor also shape women's and men's preferences and decisions. Models may thus also need to account for **gendered preferences and decision-making**, as preferences can be systematically different for men and women, even within the same household (Siddiqui 2009). For example, in an experimental role-playing game in Indonesia, Villamor and van Noordwijk (2016) found that women and men had a different

[1] This contrasts with Becker's (1981) famous 'common preference' or 'unitary' model of the household, which sees household members as sharing resources based on a common set of preferences and a single decision-making logic.

willingness to assume risks associated with changes in land use, and thus had different land use preferences. Willingness to adopt new technologies may also be gender-specific. For example, given their labor constraints, women may not be willing to adopt productivity-enhancing technologies if they increase their work burden or decreases their ability to tend to other tasks (Doss 2001). Moreover, as noted above, women and men may not have the same information; and this will shape their preferences and decisions with respect to resource management.

Hence, some models account for the gender-specificity of preferences, access to resources, and decision-making in agriculture and natural resource management, with attention paid to the underlying causes for gender differences. For example, Gladwin et al. (2002) use participatory role-playing exercises to investigate gender-specific preferences in land use. They integrate gendered disparities in access to land, credit, and other resources in a model to study how these factors affect land use patterns and consequent delivery of ecosystem services. Similarly, Baker et al. (2015) develop a model to reflect the number and type of ecosystem services related to water that are important to, and used by, different gender groups. Villamor et al. (2014) use agent-based modeling based on participatory mapping and role-playing exercises to complement quantitative data exploring the potential effectiveness of a payment for ecosystem services (PES) design in a rubber eco-certification scheme. Rather than treating the household as a unit, their simulation incorporates decision-making processes for heterogeneous households. Their results show that gender is an important factor in decision-making about land use options; hence, integrating gender considerations in their models improves the model's accuracy.

Due to the gender differences and inequalities described above, the **distribution of costs (e.g. monetary, labor or other) and benefits (e.g. consumption, income) from adopting different practices or innovations** may also be gender differentiated**.** A model predicting the impact of an innovation should reflect that this impact is likely to differ for women and men, and for different groups of women and groups of men, as gender shapes "relative female/male wages, gender differences in the distribution of time between paid and unpaid work, women's and men's shares in total household consumption" (Fontana 2015, p. 10).

Box 1: Intersectionality

In developing a model, it is critical to consider **which social relations beyond gender have an important bearing on the phenomenon under study**. An **'intersectional' analysis** that explores how gender interacts with age, education level, marital status, ethnicity, position within the household, or other salient social relations is required to understand resource management processes.

Intersectionality refers to how different axes of social marginalization (e.g. based on being a woman, being young, belonging to a particular ethnic group or following a particular religion) interact to create distinct experiences of discrimination and marginalization (Cho et al. 2013, Kabeer 2015). It means that the experiences of any individual is shaped by several aspects of their identify, such that the experiences of a better-off woman, for example, can be quite different from those of a poorer woman, or those of a young married woman different than those of an older widow.

What intersectionality implies is that a model may need to include several social categories (e.g. gender, age, socio-economic status) to describe or predict gendered outcomes. For example, Haggith et al. (2003) use the Forest Land Oriented Resource Envisioning System (FLORES) simulation model to capture interactions between rural communities in forest margins and natural resources. Based on anthropological studies that describe the rules and relationships that mediate land distribution processes, the authors integrate gender, marital status and childbearing as variables affecting how land and labor are allocated within the community. Likewise, Villamor et al. (2015) adopt an intersectional approach that puts gender and household wealth in relation to each other to understand land use decisions. In this way, the model offers greater explanatory power than it would if it accounted for social differentiation based solely on gender.

Efforts to integrate gender analyses in models often include attention to 'male' versus 'female' household headship. This information is commonly collected during household surveys and available for use in the model. Yet, while disaggregation by gender of household head has been useful for learning about these different household configurations, it overlooks gender inequalities occurring in households with two (or more) spouses, and the experiences of women in these households who typically have different strategic interests, livelihoods, and constraints than their male counterparts (Chant 2004).

In their seminal study on women's adoption of agricultural innovations in Ghana, Morris and Doss (1999) problematize research designs that survey only female-headed households because these engage with only a small sample of women, leaving behind those who live and work in dual-headed households (often referred to as 'male headed') and are the vast majority of women farmers. In their study on of banana-related disease management practices in Uganda, Kikulwe et al. (2017, p. 88) criticize the use of the household head sex to investigate gender because it ignores that "men and women within the same household cultivate and own crops either independently or jointly". The authors interview men and women from dual headed households to understand gendered adoption preferences and constraints for banana Xanthomonas wilt (BXW) control technologies. Results show that women tend to have lower adoption rates than men because of a lack of access to physical and financial assets. For example, the adoption of banana tissue culture cloned from disease-free banana plantations was more frequent in men owned banana plantations because of the high cost of acquiring this technology.

A focus on 'female-headed households' as a homogeneous group is also misleading because it tends to conflate different types of households, including those wherein women are widowed, divorced or separated, and those wherein a spouse is temporarily or permanently away on migration. Yet, these different realities have distinct implications for household resources and resource allocations as well as decision-making. Hence, Mudhara et al. (2002), in their study of technology adoption, consider households to be divided into 'male-headed,' de facto 'female-headed' (where the 'male head' is not residing on the farm), and de jure 'female-headed' (formally identified as female headed as per land ownership and inheritance laws). They further differentiate female-headed households by marital status: married women, single women, widows or siblings of absent male household heads, who will experience different levels of power and control over resources according to the higher or lower status assigned to their position by local norms and rules. In their gender-sensitive model, Mudhara et al. (2002) include several variables for labor (e.g. who is employed in plowing, planting, weeding and harvesting, and who has command and control of the necessary labor), account for gendered cash constraints, and land area availability to simulate the effects of the introduction of a new crop.

2. Collecting data to parameterize the model

A model's descriptive or predictive ability depends on the quality of the data used to populate it. **Gender-responsive sampling and data collection** are thus important considerations when developing and populating a conceptually gender-sensitive model. Questions around who to include as participants in data collection to ensure representativeness of respondents are primordial.

Doss (2014) explains principles of sex-disaggregated quantitative data collection that also apply to modeling activities relying on empirical data. Moreover, surveys, interviews and/or participatory approaches to data collection will need to overcome constraints that may preclude the full engagement of both women and men research participants. Elias (2015) explores gender-responsive strategies for data collection, which range from identifying suitable places and times to engage with women participants, to using gender-responsive language, and facilitating discussions in inclusive ways. Indeed, the ways questions are framed in data collection instruments will influence data quality.

For instance, Caldwell et al.'s (2007) model of China's CO_2 sequestration potential is based on a GIS-based integrated assessment approach that brings together five models for carbon sequestration, crop income, timber income, carbon credits, and Grain for Green (a national reforestation program that pays farmers for converting fields into forest). A complementary household survey module to assess the program's impact on different gender and ethnic groups is included, with gender-specific questions on changes in labor burdens and workloads resulting from the implementation of the Grain for Green program. Although the questionnaire includes important questions for conducting gender analyses, 92% of the survey respondents were male. Moreover, the authors note that the survey was difficult to read and understand, which may have further biased the results, as women in the area generally had less formal education (which also contributed to lower survey completion rates by women than men). Inclusive sampling schemes and data collection instruments designed with due consideration for respondents' capacities, and settings and interactions that put socially diverse participants at ease, are needed to gather data that will populate gender-responsive models.

3. Interpreting and utilizing model outputs

Finally, a gender lens is required when interpreting and utilizing model outputs. Even biophysical models, which may not explicitly include gender, may **generate outputs on phenomena that carry gender implications**. Hence, additional gender analyses may be required to supplement biophysical outputs in order to draw gender-relevant implications. For example, outputs from a model predicting changes in soil carbon as a result of increased use of inorganic fertilizer should be understood within the context of gendered soil management processes. This means recognizing that women and men from differentiated social groups (e.g. richer or poorer) will have unequal capacities to access and apply inorganic fertilizer, and that they may be impacted differently from changes in the concentration of soil carbon (Zhang et al. 2019). For other models that already explicitly include gender, the interpretation needs care. Either way, interpretations will require a solid understanding of gender relations, which may be acquired through the literature as well as through complementary data collected using methodologies that can provide rich insight into historically rooted, place-specific social relations (see, for instance, guidelines on integrating gender into biophysical research prepared by the CGIAR Research Program on Dryland Systems, 2015).

Conclusion

Gender integration in mathematical models focused on agriculture and NRM is important for research and practice to be more responsive to the realities and strategic interests of all those who the work is intended to benefit—both women and men from socially differentiated groups. Doing this requires asking the right questions about gender and conducting gender analyses to reveal the gender-specific experiences, constraints, and opportunities of women and men. For example, this means considering how gender relations shape access to resources and assets, time and mobility, interests and preferences, and ability to have voice and influence in decision-making processes. Neither women nor men are homogeneous groups, and attention to how gender intersects with other social factors, such as age or stage in the life cycle, socio-economic status, ethnicity or caste, among others, is needed for informed analyses. Ensuring adequate sampling and engagement with different social groups in data collection are critical for gender integration, as is an informed interpretation of model outputs. This brief has sought to provide a starting point towards this integration to support the development of equitable innovations, and contribute to efforts to enhance gender equality and social inclusion through agriculture and NRM.

References

Baker, T.J., Cullen, B., Debevec, L. and Abebe, Y. 2015. A socio-hydrological approach for incorporating gender into biophysical models and implications for water resources research, *Applied Geography*, 62, pp. 325-338.

Becker, G.S. 1981. *A Treatise on the Family*. Harvard University Press, Cambridge, MA, USA.

Blake, M. and Hanson, S. 2005. Rethinking innovation: context and gender, *Environment and Planning A: Economy and Space*, 37, pp. 681-701.

Caldwell, I.M., Maclaren, V.W., Chen, J.M., Ju, W.M., Zhou, S., Yin, Y. and Boland, A. 2007. An integrated assessment model of carbon sequestration benefits: a case study of Liping country, China, *Journal of Environmental Management*, 85, pp. 757-773.

CGIAR 2015. *Guidelines: Integrating Gender into Biophysical Research*. Guidelines prepared for the CGIAR Research Program on Dryland Systems, CGIAR, Montpellier, France.

Chant, S. 2004. Dangerous Equations? How Women-headed Households Became the Poorest of the Poor: Causes, Consequences and Cautions. *IDS bulletin*, 35(4), pp. 19-26.

Chant, S. 2008. The 'Feminisation of Poverty' and the 'Feminisation' of Anti-Poverty Programmes: Room for Revision?, *The Journal of Development Studies*, 44(2), pp. 165-197.

Cho, S., Crenshaw, K. and McCall, L. 2013. Toward a Field of Intersectionality Studies: Theory, Applications, and Praxis. *Signs: Journal of Women in Culture and Society*, 38(4), pp. 785-810.

Do, T.N. and Bennett, J. 2008. Estimating wetland biodiversity values: a choice modelling application in Vietnam's Mekong River Delta, *Environment and Development Economics*, 14, pp. 163-186.

Doss, C.R. 2001. Designing Agricultural Technology for African Women Farmers: Lessons from 25 Years of Experience, *World Development*, 29(12), pp. 2075-2092.

Doss, C.R. 2014. *Standards for Collecting Sex-Disaggregated Data for Gender Analysis: a Guide for CGIAR Researchers*. Brief prepared for the CGIAR Research Program on Policies, Institutions and Markets, IFPRI, Washington, USA.

Doss, C.R. and Morris, M. 2001. How does gender affect the adoption of agricultural innovations? The case of improved maize technology in Ghana, *Agricultural Economics*, 25(1), pp. 27-39.

Elias, M. 2013. *Practical tips for conducting gender-responsive data collection*. Brief prepared for the CGIAR Research Program on Forests, Trees and Agroforestry, Bioversity International, Maccarese, Italy.

Fontana, M. 2015. *Adding Gender Dimensions to Bio-Economic Modelling: Insights from the Literature*. Working paper prepared for IFPRI, Washington DC, USA.

Gershenfeld, N. 1998. *The Nature of Mathematical Modeling*, Cambridge University Press, Cambridge.

Gladwin, C.H., Peterson, J.S. and Uttaro, R. 2002. Agroforestry Innovations in Africa: Can They Improve Soil Fertility on Women Farmers' Fields?, *African Studies Quarterly*, 6(1), pp. 245-269.

Grassi, F.; Landberg, J.; Huyer. S. 2015. *Running out of time - The reduction of women's work burden in agricultural production*. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO). Available at: http://www.fao.org/3/a-i4741e.pdf.

Haggith, M., Muetzefeld, R.I. and Taylor, J. 2003. Modelling decision-making in rural communities at the forest margin, *Small-scale Forest Economics, Management and Policy*, 2(2), pp. 241-258.

Horsburgh, J.S., Leonardo, M.E., Abdallah, A.M. and Rosenberg, D.E. 2017. Measuring water use, conservation, and differences by gender using an inexpensive, high frequency metering system, *Environmental Modelling & Software*, 96, pp. 83-94.

Kabeer, N. 2015. Gender, poverty, and inequality: a brief history of feminist contributions in the field of international development. *Gender and Development*, 23(2), pp.189-205.

Kantor, P., M. Morgan, and A. Choudhury. 2015. Amplifying Outcomes by Addressing Inequality: The Role of Gender-transformative Approaches in Agricultural Research for Development. *Gender, Technology and Development*, 19(3), pp. 292-319.

Keil, A., Zeller, M. and Franzel, S. 2005. Improved tree fallows in smallholder maize production in Zambia: do initial testers adopt the technology? *Agroforestry Systems*, 64(01), pp. 225-236.

Kikulwe, E.M., Okurut, S., Ajambo S., Gotor, E., Ssali, R.T., Kubiriba, J. and Karamura, E. 2017. Does gender matter in effective management of plant disease epidemics? Insights from a survey among rural banana farming households in Uganda. *Journal of Development and Agricultural Economics*, 10(3), pp. 87-98.

Kingiri, A.N. 2013. A Review of Innovation Systems Framework as a Tool for Gendering Agricultural Innovations: Exploring Gender Learning and System Empowerment, *The Journal of Agricultural Education and Extension*, 19(5), pp. 521-541.

McCarl, B.A. 1984. Model validation: An overview with some emphasis on risk models. *Review of marketing and agricultural economics,* 52(3), pp. 153-173.

Mercer, D.E. 2004. Adoption of agroforestry innovations in the tropics: A review, *Agroforestry Systems*, 61(1–3), pp. 311–328.

Mudhara, M., Hildebrand, P.E. and Gladwin, C.H. 2002. Gender-sensitive LP models in soil fertility research for smallholder farmers: reaching de jure female headed households in Zimbabwe, *African Studies Quarterly*, 6(1), pp. 295-309.

Pannell, D., Marshall, G., Barr, N., Curtis, A., Vanclay, F. and Wilkinson, R. 2006. Understanding and promoting adoption of conservation technologies by rural landholders, *Australian Journal of Experimental Agriculture*, 46(11), pp. 1407-1424.

Pfeiffer, J.M. and Butz, R.J. 2005. Assessing cultural and ecological variation in ethnobiological research: the importance of gender, *Journal of Ethnobiology*, 25(2), pp. 240-278.

Ragasa, C., Berhane, G., Tadesse, F., Taffesse, A. S. 2013. Gender Differences in Access to Extension Services and Agricultural Productivity. *The Journal of Agricultural Education and Extension* 19(5), pp. 437–468.

Sen, A. 1990. Gender and Cooperative Conflict. In Tinker, I., Ed., *Persistent Inequality*, Oxford University Press, Oxford, United Kingdom, pp. 123-149.

Shiferaw, B., Okello, J. and Reddy, R.V. 2009. Adoption and adaptation of natural resource management innovations in smallholder agriculture: reflections on key lessons and best practices, Environment, *Development and Sustainability*, 11, pp. 601–619.

Siddiqui, R. 2009. Modeling Gender Effects of Pakistan’s Trade Liberalization. *Feminist Economics*, 15(3), pp. 287-321.

Swallow, K. and Swallow, B. 2015. Explicitly Integrating Institutions into Bioeconomic Modeling. IFPRI Discussion Paper 001420; IFPRI, Washington, DC.

Taylor, J.E. and Adelman, I. 2003. Agricultural household models: genesis, evolution and extensions’ *Review of Economics of the Household* 1(1), pp. 33-58.

Tayouga, S. J., Gagné, S. A. 2016. The Socio-Ecological Factors that Influence the Adoption of Green Infrastructure. *Sustainability*, 8(12), p. 1277.

Udry, C., 1996. Gender, Agricultural Production, and the Theory of the Household. *Journal of Political Economy* 104(5), pp. 1010-1046.

Villamor, G.B. and van Noordwijk, M. 2015. Incorporating gender specific land-use decisions in agent-based land use models, Paper prepared for the 21st International Congress on Modelling and Simulation, Australia.

Villamor, G. B. van Noordwijk, M. 2016. Gender specific land-use decisions and implications for ecosystem services in semi-matrilineal Sumatra. Global Environmental Change 39(Supplement C): 69–80. doi: 10.1016/j.gloenvcha.2016.04.007.

Villamor, G.B., Le, Q.B., Djanibekov, U., van Noordwijk, M. and Vlek, P.L.G. 2014. Biodiversity in rubber agroforests, carbon emissions, and rural livelihoods: an agent-based model of land-use dynamics in lowland Sumatra, *Environmental Modelling & Software*, 61, pp. 151-165.

Villamor, G.B., Troitzsch, K.G. and van Noordwijk, M. 2013. Validating human decision making in an agent-based land-use model, Paper prepared for the 20th International Congress on Modelling and Simulation, Australia.

Warner, J. and Campbell, D.A. 2000. Supply Response in an Agrarian Economy with Non-Symmetric Gender Relations, *World Development*, 28(7), pp. 1327-1340.

Zhang, W., Walker, D., Hernandez, C.C., Elias, M., Meinzen-Dick, R., Nkonya, E. 2019 Gendered opportunities for improving soil health - A conceptual framework to help set the research agenda. IFPRI Discussion Paper, Washington, DC, IFPRI.

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