Environmental and economic impacts of water and land management practices using an integrated model for the Tala River basin in Uruguay

Traditionally, economists relied on standard econometric methods to study land use practices and their economic impacts. Usually, this approach has fallen short when it comes to evaluating interactions and feedbacks between land use and different biophysical variables like temperature, plant evapotranspiration, crop yields, water quantity and quality, etc. Notwithstanding, integrated assessment models (IAMs) have been gaining ground in recent years since they incorporate many of these aspects into agricultural practices modeling. In the last decade, several research papers relied on this approach to model different phenomena, for example, to study the relationship between land use practices and water pollution (Rabotyagov et al. 2010, 2013, 2014; Liu et al. 2020; Lee et al. 2012; Corona et al. 2020; Griffin et al. 2020; Pastori et al. 2017; Haas et al. 2017; and Panagopoulos et al. 2011, 2014).

IAMs help represent interconnected processes from two or more domain fields (e.g: economics, agriculture, hydrology, etc) into a specific environment. More specifically, according to Kling et al. (2017), IAMs can be described into three main layers. A first layer describes land use production practices, influenced by agents' preferences, economic variables such as crop prices or input costs as well as land use regulation imposed by the government. Decisions made into this layer influence many biophysical processes modeled into a second one. For example, plant growth, crop yields or water quantity and quality within a field depends on land use management. Lastly, outputs from the previous processes are important to determine economic variables contained into a third layer including economic benefits, prices, etc. Such variables, in turn, determine land use management (first layer). This approach is particularly useful to analyze possible unintended land use management spillovers since IAMs account for (generally) omitted linkages between economic variables and the environment.

We present an application of an IAM consisting of integrating an hydrological model (SWAT, version 2012) with an economic model of farmer's decision making in which their input variables are affected by output variables of the SWAT model, and a set of other exogenous variables relevant for the problem at hand (prices, policy parameters, etc.).

We calibrate this application to the Tala River basin, a micro basin of 12,000 ha (3,200 ha under crops), located within a farm operation in the northwest region of Uruguay. It belongs to a prominent agricultural area where the main crops are rice, soybean, and corn, and extensive areas of natural rangelands and pasture are devoted to livestock production.

All rice in Uruguay is produced with surface irrigation. Additionally, given the high inter-annual rainfall volatility in the basin, supplementary irrigation is deemed as a beneficial technology to improve yields and reduce profit volatility in other crops such as corn and soybeans typically produced under rain-fed systems. This is the case because it helps to avoid significant yield losses, particularly in dry years (Gimenez, 2012). As noted by previous literature about irrigation practices in Uruguay, the latter becomes more important when we take into account farmer's risk aversion (Rosas et al. 2017; Souto et al. 2021).

Two reservoirs are located within the basin, with one of them (12 million cubic meters) being the main source of irrigation. The typical irrigation practice for corn consists of surface irrigation and is based on soil demand seeking to maintain a saturated soil. However, deficit irrigation is used for soybeans, and corn is irrigated to fully satisfy its water demand.

We highlight the importance of this basin because it allows us to analyze different land use and water management scenarios, for example, the economic and environmental consequences of introducing an additional source of water demand to the existing rice surface irrigation, consisting of supplementary irrigation to soybean and corn.

We analyze a set of scenarios relevant for farm and water management decision making. First, one of the determinants of water use efficiency relates to water losses in conduction. In fact, when conduction is performed in channels, these losses tend to be significant depending on the type of channels. We set up a set of scenarios with levels of irrigation efficiency in water conduction ranging between 60% and 100% and evaluate their effects in farmers profit and water quantity at the basin outlet.

Second, every season, given the available volume in water reservoirs, farmers decide on the area to plant and irrigate, taking the per-hectare water rate as given. However, it is also possible to change the irrigation area by setting different irrigation rates. We analyze a set of scenarios involving different irrigation rates in each crop and evaluate their effects on profits and water quantity at the basin outlet. One scenario involves irrigating all crops to fully satisfy their water demand. Other scenarios involve deficit irrigation for soybean and corn. Finally, two more scenarios, one consisting of irrigating only rice and corn while keeping soybean as rain-fed, and another scenario consisting of irrigating only rice.

A key benefit of irrigation in Uruguay is the stabilization of yields in the case of corn, and to a lesser extent soybeans. In this line, the main attractiveness of irrigation is not so much to increase yields in normal years but to act as insurance against significant losses in dry years. This benefit seems to be increasingly valuable with the advent of climate change, which for the case of Uruguay, entails a higher frequency of extreme events, including droughts. Dry years have opposing effects on irrigation. While it is in dry years in which the benefits of irrigation (as opposed to rain-fed production) are more significant, the same years may result in lower quantities of water flowing into the reservoirs and thus available for irrigation, limiting the potential benefits of the investments in infrastructure. It is therefore critical to empirically assess the impacts of climate change as both increasing the value of irrigation as an insurance while at the same time eroding its effectiveness by limiting the amount of water available. This trade-off will be analyzed through carefully designed scenarios of climate change using the integrated assessment model that is being constructed.

IAM assessments are becoming more extensively used in economics and in turn, have been providing key inputs for policy design and decision-making in a variety of settings. While these models have been extensively used in developed countries, the applications are much newer in developing countries in general, and Latin American countries in particular. Therefore, conclusions from our analysis are likely to generate an interesting debate about the methods employed and the implications for policy analysis.

References

Giménez, L. (2012). ¿Cuánto estamos perdiendo por no regar cultivos en Uruguay? Riego en cultivos y pasturas: 2º Seminario internacional, 33-41.

Griffin, R., Vogl, A., Wolny, S., Covino, S., Monroy, E., Ricci, H., Sharp, R., Schmidt, C., y Uchida, E. (2020). Including additional pollutants into an integrated assessment model for estimating nonmarket benefits from water quality. Land Economics, 96(4):457–477.

Haas, M. B., Guse, B., y Fohrer, N. (2017). Assessing the impacts of best management practices on nitrate pollution in an agricultural dominated lowland catchment considering environmental protection versus economic development. Journal of Environmental Management, 196:347–364.

Lee, L. Y., Ancev, T., y Vervoort, W. (2012). Evaluation of environmental policies targeting irrigated agriculture: The case of the Mooki catchment, Australia. Agricultural water management, 109:107–116.

Liu, H., Zhang, W., Irwin, E., Kast, J., Aloysius, N., Martin, J., y Kalcic, M. (2020). Best management practices and nutrient reduction: An integrated economic-hydrologic model of the Western Lake Erie basin. Land Economics, 96(4):510–530.

Kling, C. L., Arritt, R. W., Calhoun, G., y Keiser, D. A. (2017). Integrated assessment models of the food, energy, and water nexus: A review and an outline of research needs. Annual Review of Resource Economics, 9:143–163.

Panagopoulos, Y., Makropoulos, C., Gkiokas, A., Kossida, M., Evangelou, L., Lourmas, G., Michas, S., Tsadilas, C., Papageorgiou, S., Perleros, V., et al. (2014). Assessing the cost-effectiveness of irrigation water management practices in water stressed agricultural catchments: the case of Pinios. Agricultural Water Management, 139:31–42.

Panagopoulos, Y., Makropoulos, C., y Mimikou, M. (2011). Reducing surface water pollution through the assessment of the cost-effectiveness of BMPS at different spatial scales. Journal of Environmental Management, 92(10):2823–2835.

Pastori, M., Udías, A., Bouraoui, F., y Bidoglio, G. (2017). A multi-objective approach to evaluate the economic and environmental impacts of alternative water and nutrient management strategies in africa. Journal of Environmental Information 29(1):193–201.

Rabotyagov, S., Campbell, T., Jha, M., Gassman, P.W., Arnold, J., Kurkalova, L., Secchi, S., Feng, H., y Kling, C. L. (2010). Least-cost control of agricultural nutrient contributions to the Gulf of Mexico hypoxic zone. Ecological Applications, 20(6):1542–1555.

Rabotyagov, S. S., Campbell, T. D., White, M., Arnold, J. G., Atwood, J., Norfleet, M. L., Kling, C. L., Gassman, P. W., Valcu, A., Richardson, J., et al. (2014). Cost-effective targeting of conservation investments to reduce the northern Gulf of Mexico hypoxic zone. Proceedings of the National Academy of Sciences, 111(52):18530–18535.

Rabotyagov, S. S., Valcu, A. M., y Kling, C. L. (2013). Reversing property rights: practice-based approaches for controlling agricultural nonpoint-source water pollution when emissions aggregate nonlinearly. American Journal of Agricultural Economics, 96(2):397–419.

Rosas, J. F., Sans, M., y Arana, S. (2017). Quantifying the Benefits of Supplemented Irrigation due to Less Volatile Yields: A Prospect Theory Approach Applied to Summer Crops in Uruguay. Retrieved from https://ageconsearch.umn.edu/record/259122/files/Abstracts_17_05_24_17_45_38_41__167_57_116_21_0.pdf.

Souto, A., Carriquiry, M. A., & Rosas, J. F. (2021). Assessing the Impact of Agricultural Intensification on Water Pollution: An Integrated Model Assessment of the San Salvador Basin in Uruguay. Retrieved from: https://ageconsearch.umn.edu/record/314037/files/Abstracts_21_06_29_16_59_31_10__190_133_248_19_0.pdf