Proposal for AI-Informed Discovery and Inquiry Seed Grant 2025
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Project Title: A Deeper Dive on Deep-Learning Solution Methods for Heterogeneous Agents Macroeconomic Models

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Proposal Narrative

Statement of the Problem or Area of Investigation. Economists have almost universally adopted the methodological approach of comparing actual behavior of agents (consumers; firms) to the behaviors that would be rationally computed by an agent who had perfect information and unlimited ability to process that information. But the problems faced by either households or firms are astonishingly difficult (mainly because the future is so uncertain). Of course, AIs also aim to solve extraordinarily difficult problems, and they use tools with a strong family resemblance to the tools economists have used. Our area of investigation is to compare the solutions economists have obtained using traditional methods compare to the solutions that would be computed by an AI trying to solve the same problem. Our expectation is that we will either find that AI solution methods are much more powerful, or that they go off the rails and fail to find the correct truly rational solution. Either finding would be interesting in the rapidly developing AI-in-economics literature.

Project Goals/Objectives and Methods. Our goal is to understand the differences between solutions to a canonical model that can be obtained (painfully) using tools that are known to provide exactly optimal solutions (the economists' traditional approach) to the solutions produced by AI tools.

As for method, we already have a case of a model – the Krusell and Smith (1998) model – that has been solved using both technologies,[1] but little is known about the circumstances in which the two solutions will be similar and those in which the AI solution differs markedly from the traditional "optimal" solution.

While the authors of the AI solution find that the results of their approach are similar to those obtained by economists' methods, they do not provide much insight into the reasons for, or the robustness of, this result. Until the answers to those questions are better understood, economists will be reluctant to adopt AI technologies as a respectable alternative to solving models in the traditional way.

Attractiveness for Future Funding. Funding will flow to this area only when there is some practical wisdom about what works and what doesn't. Our aim is to build that practical wisdom, in the context of a familiar model. Once the differences between AI-based solutions and traditional solutions is understood, a wide path for future funding becomes available because a little knowledge of which approaches work better in which contexts should give funders more certainty about which projects are promising and which are not.

The field would greatly benefit from a proper *interpretation* of the neural network's solution. That is, if the second moment of the wealth distribution *isn't* relevant, but the neural network found information of the same dimensionality that *is* relevant, then *what is that information*? Maliar, Maliar, and Winant (2021) are silent on this critical question, the answer to which would inform further development of both economic theory and computational methods. (See Reiter (2010) for

[1] A special issue of the *Journal of Economic Dynamics and Control*, Den Haan, Judd, and Juillard (2010), was devoted some years ago to comparing alternative solution methods, which gives us a rich basis for comparison.

insightful work on this point). That is, if we have a better idea of *what to look for* based on the neural network's solution to one model, these insights can be applied to other models *whether or not* a neural network is used to solve them.

I am particularly well positioned to accomplish the goals outlined in this proposal, for several reasons. I am one of the leading theorists on consumption-saving models (Carroll (1997)), as well as the developer of foundational methods for their efficient solution (Carroll (2006)). Second, I am the PI for Econ-ARK (`http://econ-ark.org`), a project that produces open source software for solving heterogeneous agents models (the `HARK` Python package). Furthermore, I already have an implementation of the Maliar, Maliar, and Winant (2021) paper and several implementations of the Krusell-Smith model readily at hand, and am familiar with things like the solution time each takes. Finally, I am well connected to the authors of Maliar, Maliar, and Winant (2021), as well as to experts who are very knowledgeable in all the domains necessary to complete the project (see the budget justification for details of the help I anticipate obtaining for completing the project).

Evidence of plan to secure follow-on funding. The Econ-ARK project is currently funded by a generous corporate sponsorship from T. Rowe Price, and has previously received a large grant from the Sloan Foundation, to whom we are applying for a second grant.

We have drafted a letter of intent to the Sloan Foundation for a grant to fund further development of our existing tools for solving models of the kind described herein. Part of our development plan includes building a structure in which it would be easy to compare alternative solution methods to the same model. We also have good reason to hope for further funding from T. Rowe Price, whose corporate sponsorship of the project was motivated by the fact that the core of our toolkit is the computer code for solving an optimal saving and portfolio problem for households – something TRP (and other financial firms) are beginning to try to do themselves.

Post-Award Requirements

The Econ-ARK project has recently produced a draft report for a grant previously received from the JHU Open Source Programs Office. A review of that report should inspire confidence in our ability to produce a high quality report when this project concludes.

Third, I have recently been installed as the president of the Society for Computational Economics (SCE), taking over from Lilia Maliar (of Maliar, Maliar, and Winant (2021)), in which role I plan to use the tools in my power to foster more research in this area. I am also well connected to the small set of people who are well-versed in all of the computational and mathematical tools necessary to accomplish this analysis.

Budget and Budget Justification

I am requesting $25,000 in funding from the AI-Informed Seed Grant program. These funds will primarily be spent on labor costs for two collaborators, whom I will direct and supervise:

- Matthew N. White (JHU PhD 2014), a full time employee of Econ-ARK who was the primary developer for the `HARK` software package and has collaborated with me on heterogeneous agents macroeconomic research projects.
- Marc Maliar (UChicago BA 2022), an aspiring economist who served as a programmer for the TensorFlow code used for Maliar, Maliar, and Winant (2021) and has intimate knowledge of its development.

Marc's primary task is simply to "onboard" White and me, so that we are familiar with the MMW TensorFlow code structure and can reproduce its results locally. We already have our own code for a benchmark version of the Krusell-Smith model, providing an additional source of verification. I will then work with Dr. White to more fully characterize the nature of the differences between solutions produced by the methods.

Conservatively budgeting $3000 of Marc Maliar's time to bring us up to speed (and for additional consulting later), and providing my own research time gratis, this leaves over six weeks of Dr. White's full time. Given the well bounded nature of this seed project, our "hot start" on the work, and the importance of this project in attracting further funding from (e.g.) the Sloan Foundation and T. Rowe Price, I am quite confident that we can produce a thorough report in the short time frame.

References

Carroll, C. D. (1997). "Buffer-Stock Saving and the Life Cycle/Permanent Income Hypothesis*." *The Quarterly Journal of Economics*, 112(1): 1–55.

Carroll, C. D. (2006). "The method of endogenous gridpoints for solving dynamic stochastic optimization problems." *Economics Letters*, 91(3): 312–320.

Christopher D. Carroll, Alexander M. Kaufman, Jacqueline L. Kazil, Nathan M. Palmer, and Matthew N. White (2018). "The Econ-ARK and HARK: Open Source Tools for Computational Economics." In Fatih Akici, David Lippa, Dillon Niederhut, and M. Pacer, editors, "Proceedings of the 17th Python in Science Conference," pp. 25 – 30.

Den Haan, W., Judd, K., and Juillard, M. (2010). "Computational Suite of Models with Heterogeneous Agents: Incomplete Markets and Aggregate Uncertainty." *Journal of Economic Dynamics and Control*, 34(1).

Krusell, P. and Smith, A. A., Jr. (1998). "Income and Wealth Heterogeneity in the Macroeconomy." *Journal of Political Economy*, 106(5): 867–896.

Maliar, L., Maliar, S., and Winant, P. (2021). "Deep learning for solving dynamic economic models." *Journal of Monetary Economics*, 122: 76–101.

Reiter, M. (2010). "Approximate and Almost-Exact Aggregation in Dynamic Stochastic Heterogeneous-Agent Models."