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# “Write Your Model Almost as You Would on Paper and Dynare Will Take Care of the Rest!”

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## **Abstract**

According to its creator Michel Juillard, Dynare is a “pre-processor and a collection of routines” aimed at solving and estimating non-linear rational expectation models. This article focuses on the role of Dynare in the dissemination of dynamic stochastic general equilibrium (DSGE) models in academia and policymaking institutions. The case of Dynare highlights how the dissemination across the profession of theoretical principles and modelling practices cannot be thought independently from (at least) two general issues that involve designing computer tools for macroeconomics: tractability (i.e. the existence of a computer algorithm that can solve a mathematical problem using ‘reasonable’ resources) and portability (i.e. the material ability of circulating and transferring a computer algorithm across models, people, and institutions). In this article, we document how the origins and the development of Dynare over three decades was guided by these two issues.

**Keywords:** History of macroeconomics, DSGE models, Dynare, computerization of economics

**JEL Codes:** B22; B23; C63; E37

“Ease of Use. Write your model almost as you would on paper and Dynare will take care of the rest!”

Dynare’s Homepage<sup>1</sup>

What does it take for a class of models to become dominant? Several computation-oriented macroeconomists have pondered this question in the context of Dynamic Stochastic General Equilibrium (DSGE) models, with a particular emphasis on the significance of computer tools. For instance, Jesus Fernandez-Villaverde (2009, 14) explains how Dynare, “an extraordinary tool developed by Juillard and a team of collaborators, [enables] a moderately experienced user [to] write code for a basic real business cycle model in an hour and compute the approximated solution in a few seconds” (see also Villaverde et al., 2010). Likewise, Christopher Carroll and Edmund Crawley (2017, 77) assert that “much of the reason for the ubiquity of [DSGE] models is the creation of the DYNARE toolkit, which vastly simplified construction of such models.” Carroll also stressed the importance of establishing a “grammar” to describe heterogeneous-agent models. As he explained in a personal communication, “That’s what Dynare provided for representative agent models.”

These scholars underline the significant role played by Dynare in promoting the dissemination of DSGE models. However, the exploration of objects like Dynare have been insufficient in the history of macroeconomics. Previous contributions have focused on academic controversies surrounding theoretical and methodological issues (e.g., Duarte and Lima, 2012; Backhouse and Boianovsky, 2013; De Vroey, 2016) as well as the development of empirical and modelling practices, particularly within policymaking institutions (e.g., Boumans and Duarte, 2019). While these accounts occasionally acknowledge the importance of computers and software, they rarely address these aspects directly.<sup>2</sup> Our article addresses this gap, by documenting the history and role of a specific “software”—Dynare—in the evolution of macroeconomics.<sup>3</sup>

Since its inception in the early 1990s, the team behind Dynare has expanded over the years, under the leadership of Michel Juillard; they now advocate for Dynare as *software* that allows macroeconomists to “write a model as [they] would on paper.” Yet the authors mentioned above also refer to Dynare as a toolkit, even a “grammar,” while Juillard (1996, 1) called it a “program” and later a “collection of routines” (Juillard 2004). This varied terminology suggests that there is more to uncover in the history of economics beyond just writing the history of “a software”. This underscores the necessity of investigating what “makes” a “software”, that is, the broader array of tools, methods, and technological changes that constitute a computer-tool like Dynare, and enable it to shape the growth and dissemination of macroeconomic concepts and models. Our article does so by meticulously documenting the motivations drove the development of Dynare, through interviews, technical documentation, and internet archives.

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<sup>1</sup> <https://www.dynare.org/> [retrieved 29/01/2022].

<sup>2</sup> A notable exception is the comprehensive work by Charles Renfro (2003; 2004) on the development of econometric software, which covers software used by macroeconomists among others. Another perspective on the evolution of macroeconomics, developed notably by political scientists, discusses how the dissemination of a given class of models is driven by factors pertaining to ideologies, politics, or the sociology of the profession (e.g., Best, 2020; Helgadóttir and Ban, 2021). In these accounts, computer tools are never mentioned.

<sup>3</sup> The role and evolution of hardware is not addressed in this paper, though it represented another crucial aspect in macroeconomists’ practices. See Duarte and Sergi (this issue).

We start by exploring what led French macroeconomists to embrace rational expectations, even amidst a dominant backdrop of Keynesian and disequilibrium ideas in the 1980s. We highlight that among the pioneers who incorporated the rational expectations hypothesis into their models—especially those relating to investment (Malgrange and Villa, 1984; Autume and Michel, 1986; Laffargue and Malgrange, 1987 among others)—were economists affiliated with CEPREMAP, a French research centre cooperating with two key policymaking institutions—the Commissariat Générale au Plan and the French Treasury (Direction de la Prévision)—as well as the University of Paris 1. These macroeconomists grappled with the challenge of handling model endogenous variables whose values depended on all expected future values in settings with infinite time-horizon. We frame the challenge faced by French macroeconomists, as by their colleagues in other countries, as a two-fold issue.

The first challenge was *tractability*, which involved solving these models using ‘reasonable’ resources: that is, developing and implementing new solution algorithms that would run, fast enough, on existing computers, to generate reliable forecasts and numerical results.<sup>4</sup> However, these algorithms initially remained niche and technical at a time when coding skills in academia and policymaking institutions were scarce. The second challenge thus involved making these algorithms *portable*, that is, enabling their material circulation and transfer across models, people, and institutions. To address these challenges, Juillard devised a parser that gradually evolved into a collection of routines, and eventually, a comprehensive software. The actors involved rarely separated *tractability* (algorithms) from *portability* (the circulation of algorithms); instead, Dynare was developed over the years as a unified computer tool addressing both concerns.

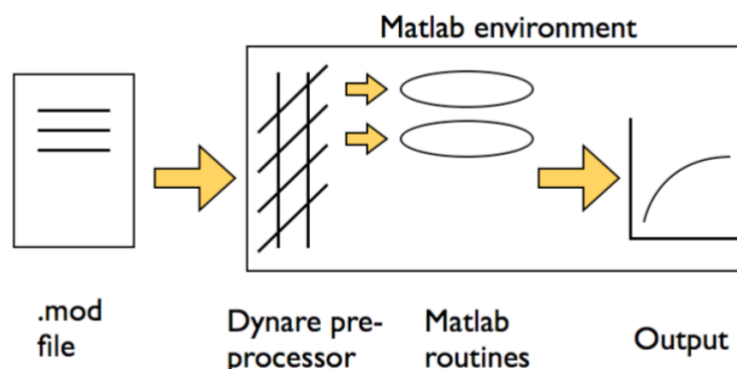
The first section of our paper documents how Jean-Pierre Laffargue proposed a novel solution to the tractability challenge, based on the Newton-Raphson algorithm. Laffargue (1990)’s method provided the steppingstone for the development of Dynare, which was initiated by Michel Juillard in the early 1990s. Juillard’s primary objective was to improve the portability of Laffargue’s method by elaborating a pre-processor—an intuitive user interface (or front-end) designed to ‘translate’ (to parse) macroeconomists’ modelling language into computer code that could be executed by a general purpose mathematical software.<sup>5</sup> Macroeconomists thus gained the ability write the equations of their models in plain text language (in what then become known as the “.mod file”), using similar notations as those they would usually employ on paper. Dynare would then turn the .mod file into a code executable by mathematical software. This architecture (summarized by Figure 1) represented a crucial first step in enhancing the portability of Laffargue’s original method. It significantly reduced the “entry cost” for economists in terms of coding skills, and made the application of Laffargue’s method to large-scale models less time-consuming.

### **Figure 1: Dynare Pre-Processor System**

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<sup>4</sup> See Cherrier (2023) for a history of how economists came to see tractability as a virtue of economic models during the 20<sup>th</sup> century, and a discussion of how the term was redefined in the process.

<sup>5</sup> The pre-processor itself is written in C language (later, C++).



Source: *Dynare 4.0 beta version documentation (Mancini-Griffoli, 2007, 3)*

During the 1990s, the first version of Dynare garnered attention from two communities: one was the International Monetary Fund’s Modelling Unit; the other, a growing community of computational economists gathering around the newly founded Society for Computational Economics (SCE). These interactions fostered both an increasing circulation and the continuous development of Dynare, as we show in the second section of our article.

In the third and final section, we illustrate how the developments of Dynare in the 2000s coincided with the emergence of the DSGE approach (*à la* Smets and Wouters). It thus provided a tailored solution to the portability challenge faced by such models, especially across policymaking institutions such as central banks. We highlight the reasons behind Dynare’s wide dissemination, including direct collaborations with central banks and the stabilization of a Dynare team working collectively.

The history of Dynare documented in this article shows that computer tools do not simply materialize as a *deus ex machina*, as some technical progress fully exogenous to the field of macroeconomics (Backhouse and Cherrier, 2017; Sergi, 2020, 180). Instead, we illustrate how a computer tool like Dynare was shaped by macroeconomists themselves. These developments were closely intertwined with their theoretical and methodological pursuits, as well as the needs of policymaking institutions. From the outset, Dynare was envisioned as a means to facilitate the development and usage of macroeconometric models for policy routines (planning, forecasting, scenarios, etc.). Our case study highlights the driving role of policymaking institutions in the overall evolution of macroeconomics, as already pointed out by historical scholarship (see e.g., Boumans and Duarte, 2019). Moreover, as in other contributions to this special issue, emphasizing the role of Dynare in the history of macroeconomics also brings to the fore previously ‘hidden’ figures: it shifts the focus away from US-based (mostly academic) macroeconomists and highlights the key role played by French-based macroeconomists working for policymaking institutions.

## 1. Making Non-Linear Rational Expectations Models Tractable: The Quest for Solution Algorithms

Since the 1970s, macroeconomists have built on the theoretical work of Lucas and Sargent (Hoover 1988; Duarte and Lima 2012; De Vroey, 2016) by exploring multiple techniques to address the tractability issue raised by rational expectations models. These models require considering all expected future values when determining present time values of endogenous variables, a task that becomes increasingly complex with larger number of variables, non-linear

relationships, and uncertainty. Although solutions for linear rational expectations models were already available by the late 1970s (see Hansen and Sargent, 1980a; 1980b; Wallis, 1980; Blanchard and Kahn, 1980), the complexity of early non-linear rational expectations models meant that these models were often reduced to perfect foresight.

In the 1970s, macroeconomists primarily relied on shooting methods, which focused on the dynamic aspects of the models that needed to be solved. These models were solved sequentially and iteratively, by adjusting the initial value of the control variables until an equilibrium path that satisfies the terminal condition was found.<sup>6</sup> While these methods were increasingly used in the 1980s, they faced competition from techniques imported from numerical mathematics, based on iterative relaxation methods. These techniques were first imported by US economists, such as Ray Fair and John Taylor (Fair, 1979; 1984; Fair and Taylor, [1980] 1983), and later extended, applied, and popularized by UK macroeconometricians involved with the ESRC Modelling Bureau based at University of Warwick. This group included Stephen Hall, Paul Fisher, Andrew Hughes Hallett, John Whitley, and Kenneth Wallis (e.g., Hall, 1985; Wallis, 1986; Fisher and Hughes Hallett, 1987).

Relaxation methods had long been used in physics and engineering (Keller, 1976) to solve dynamic systems. The basic idea was to simplify the dynamic system by treating it as a static system of equations, disregarding the recursive structure emphasized in shooting methods. In macroeconomics, the process started with defining an initial set of expectations and an approximate equilibrium path with arbitrary values for the endogenous variables. The algorithm iterated on the endogenous variables until it finds a path that satisfies the system equations with sufficient precision. The expectations were updated to match the estimated equilibrium path, and the process was repeated until the model converged to a consistent rational expectations equilibrium path, where expectations were nearly identical to the endogenous variable values. The earlier versions of relaxation methods in a non-linear perfect foresight framework developed by Fair, Taylor, Hall or Fisher used the Gauss-Seidel algorithm. Alternative approaches differed primarily in how often the set of expectations was iterated. Fair and Taylor's method updated the set of expectations once the estimated equilibrium path had stabilized, whereas Hall's method updated expectations after every modification of the estimated equilibrium path. Both algorithms demonstrated linear convergence, if achieved at all.

Recognizing the potential value of rational expectations in informing policy decisions, a group of French macroeconomists from CEPREMAP set out to enhance the numerical methods employed in economics. They focused on developing faster and more reliable computational techniques for solving a new prototype model with perfect foresight, ensuring both the uniqueness of the resulting solution and the convergence of the algorithm.

CEPREMAP had been founded in 1969 as the result of the merger between two existing research centres, CEPREL and CERMAP.<sup>7</sup> It aimed to provide valuable economic analysis and

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<sup>6</sup> In the case of an infinite horizon problem (especially an infinitely-lived representative agent model) with locally unique solution (saddle-path stable equilibrium), the terminal condition was replaced by a value arbitrarily close to the steady state.

<sup>7</sup> CEPREL and CERMAP were both independent of government institutions and purposefully designed to avoid "bureaucratic burden" while conducting research (Laffargue, interview). Economists were hired on private contracts, and funding was brought through projects and grants. CEPREMAP was able to acquire a mainframe computer at a time some government institutions still did not have access to such equipment. It was employed for conducting econometric work.

research to multiple French government institutions involved in macroeconomic policies. This included the Commissariat Général au Plan, the main economic policy-advisory agency in France created under the leadership of Charles De Gaulle and Jean Moulin in 1946, and the Direction de la Prévision (DP hereafter), the French Treasury’s research unit for macroeconomics, which has been operational since 1966.<sup>8</sup> During the 1970s, many of these institutions built macroeconomic models with varying degrees of sophistication, theoretical inspiration, and scope. These models were routinely used to inform economic policy decisions, including those associated with the French overarching economic planning process.<sup>9</sup>

CEPREMAP lead researcher Pierre Malgrange was then actively involved in establishing, using, and evaluating such models. With his CEPREMAP colleague Pierre-Alain Muet and with Michel Deleau (Ecole des ponts et chaussées), he developed a *maquette* (small size core model) of all French models in use at policymaking institutions, referred to as the Deleau-Malgrange-Muet’s model (DMM; Deleau et al., 1981).<sup>10</sup> This “model of models” or a “benchmark model” (Deleau et al., 1981, 54), employed a limited number of equations to map the underlying theoretical structure common to most existing French large-scale macroeconomic models.<sup>11</sup> The DMM *maquette* described this common structure as a dynamic IS/LM model, combining short-term Keynesian (or demand-driven) mechanisms with long-term adjustment to a balanced growth path, determined in line with the principles of the neoclassical growth model. Deleau et al. (1981, 61) noted that this long-term horizon remained implicit in most existing models. Because DMM offered explicit ties between the short and the long run, it raised questions on how to address expectations under perfect foresight.

By the 1980s, rational expectations had become well-known in France (see e.g. the review by d’Autume, 1986, and the contributions by Gourieroux et al., 1982; Broze et al., 1985; 1990). However, rational expectations were not yet integrated into the French macroeconomic models used for policymaking. Indeed, rational expectations (and, more broadly, propositions of the new classical economics) faced resistance from some influential figures in France, both from academia and policy circles, such as Edmond Malinvaud (Renault, 2020; 2022). Alternative approaches, such as disequilibrium theory, had also emerged as competitors (see e.g. Boianovsky and Backhouse 2013; Plassard et al., 2021; Goutsmedt et al., 2021). Some institution, in particular the Direction de la Prévision, were however “interested” in exploring

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<sup>8</sup> These cooperations involved a larger set of institutions. Some were under the direct administrative authority of the Commissariat Général au Plan—such as the CORDES program, dedicated to founding external research (see Bezes and Montricher, 2005). Other agencies were independent—such as INSEE, the main French statistical office. On the history of French planning, see e.g. Desrosières (1999).

<sup>9</sup> Those models included Zogol (Herzog and Olive, 1966), Deca (Billaudot 1971), Star (Bouille et al. 1974) for DP’s models, Fifi (Aglietta and Courbis, 1969)—notably documented by Angeletti (2021)—and DMS (Charpin et al., 1976) for INSEE’s models. Despite close cooperation between DP and INSEE, the two agencies focused on different areas. INSEE concentrated on the medium-term projections, primarily for planning purposes, while the DP focused on short-term projections, which informed fiscal policy decisions. Subsequently, INSEE developed a macroeconomic model, METRIC (Ménil and Nasse, 1976), which drew inspiration from the US tradition (Goutsmedt et al., 2021).

<sup>10</sup> The CEPREMAP-based project was set up with the help of the CORDES program. Malgrange, in collaboration with Deleau, authored a textbook on macroeconomic modelling (Deleau and Malgrange, 1978), which he used in his course at ENSAE to train those economists who later served in various French public administrations. For a more comprehensive view of Malgrange’s list of research contributions, see Laffargue and Morin (2020).

<sup>11</sup> All quotes from texts originally written in French have been translated by the authors of the present article.

rational expectations, though they were sceptical about concrete applications (Laffargue, interview; Pujol, interview). They were concerned with concrete applications and doubted the ability of such models to perform the same tasks (simulation, forecasting) as the existing ones. To address this concern, Malgrange and his CEPREMAP colleague Jean-Pierre Laffargue drew on the example of the DDM model and embarked on the development of an expectations-augmented prototype model. The project, initiated in 1983, was funded by the Commissariat Général au Plan and the Direction de la Prévision.

Laffargue joined CEPREL in 1967, after graduating in aeronautical engineering and economics, despite having no prior experience in macroeconomic modelling.<sup>12</sup> Along with Malgrange, he sought to re-examine the theoretical foundations of French macroeconomic modelling. They explored different assumptions on expectations (adaptive vs rational) and their implications for the economic dynamics (Laffargue and Malgrange, 1987). For instance, they highlighted how a model with rational expectations would result in quicker adjustments in consumption and investment following a policy change. They studied the model's dynamics through a linearized version, and the small size of the problem allowed for a simple paper-and-pencil solution. The prototype was completed in 1985, and in 1987, with funding from the Commissariat Général au Plan, the duo began building a larger version that was to deal with rational expectations dynamics with other computational methods (Laffargue, interview).

Malgrange and Laffargue were joined by Thierry Pujol, a former student of Malgrange at Ecole Nationale de Statistique et d'Administration Economique (ENSAE) and an economist at the DP's Bureau of Economic Projections.<sup>13</sup> While Malgrange and Pujol worked on the theoretical structure of the model, Laffargue focused on the methods for solving and simulating the model. The computational challenge created by rational expectations and non-linearity was not well-known at the time in France: since large-scale models did not include rational expectations, there had been few developments of computational practices similar to those that had started in the US and in the UK (Laffargue, interview).<sup>14</sup> Laffargue recalls reviewing these latter works and finding them “not very satisfying:”

There was much tinkering involved ... These methods weren't robust ... My first idea was to use shooting methods. But the problem [with these methods] was that, if you made a very small error in the beginning, your model would never converge. Also, you had to choose cut-off periods—say, 5 years; and

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<sup>12</sup> While working at CEPREMAP, he also held academic positions at Université Paris Dauphine (1971-1979), Université de Lille 1 (1979-1983), and Université Paris 1 Panthéon-Sorbonne (from 1983 to present).

<sup>13</sup> The Bureau of Economic Projections was the administrative unit (consisting of 5 to 6 economists) who produced medium term forecast for the French economy that the French government used to build its fiscal policy. The short-term forecasts were produced independently by INSEE. Pujol (interview) recalls that, by that time, the intellectual atmosphere at the DP and at the Bureau of Economic Projection was clearly one of scepticism towards large scale macroeconomic models, and sensed an “intellectual pressure” in favour of designing rational expectations models.

<sup>14</sup> There was however an increasing awareness that modellers in the US and in the UK were able to overcome computational challenges (Laffargue, interview). For instance, the DP had started, since 1986, regular meetings with the UK Treasury, especially driven by the interest in UK rational expectations models and optimal control techniques (Pujol, interview). Similarly, in academia, British-French relationships were already well-developed, with regular contacts and joint initiatives, especially in the field of macroeconomics and in relation to policy-oriented debates. See for instance Goutsmedt et al. (2021) on the Anglo-French Colloquium, the Centre for Economic Policy Research (CEPR), and the beginnings of the journal *Economic Policy*.

this was done by a long trial-and-error process ... And, if you changed the model, you needed to start over. It was not general enough. So, relaxation methods seemed better. ... The problem with [existing relaxation] method was that sometimes it converged, sometimes it did not, even when one started in the vicinity of the solution. ... But, of course, the advantage was that they were simpler to program. (Laffargue, interview)

Laffargue decided to start anew by exploring available methods in applied mathematics. His main source of inspiration came from a classic book in his native field of engineering: *Numerical Recipes* (Press et al., 1986). Its chapter 16, which focused on “Two-point boundary value problems,” introduced shooting and relaxation methods, as well as the Newton-Raphson algorithm. Laffargue (interview) describes as a “revelation” that solving their differential equation model was no different from the common problem engineers and physicists faced.<sup>15</sup> This aspect of our story is reminiscent of earlier transfers between engineering techniques and macroeconomics, such as Bellman’s equations (Klein 2007; 2015; see also Boumans, 2020 on the early years of rational expectations).

Laffargue adapted the Newton-Raphson relaxation method, which he found in *Numerical Recipes*, to solve large non-linear perfect foresight models. His method involved a sequence of linear approximations of the initial dynamic system, where each linearization was performed in the neighbourhood of the solution found at the previous step, except for the first step where an arbitrary starting point is chosen. As a result, the Jacobian of the dynamic system (i.e. the value of the first partial derivatives) had to be constantly recalculated. Compared to the Gauss-Siedel algorithm underlying Fair and Taylor’s or Hall’s methods, the Newton-Raphson algorithm offered faster and more stable convergence while requiring less stringent conditions. However, it required storing a larger amount of information at each step. Laffargue was able to overcome this difficulty by leveraging the sparsity pattern of the Jacobian matrix, which is common in rational expectations models. By exploiting the matrix’s many zero entries, the Newton-Raphson algorithm turned out to be less computationally expensive, and thus more tractable.

Laffargue’s goal went beyond mere robustness. He aimed to create a “more general, clearer and transparent” approach that could handle models of any size or complexity, including the challenging *maquettes* fashioned at CEPREMAP. Unlike existing methods, which were often tailored to specific models and required extensive recalibration when the model changed or evolved, Laffargue (interview) sought to develop a more portable method that could be applied universally with equal ease and effectiveness, regardless of the model. Eventually, he published his method in French in the journal of the INSEE (the French National Statistical Office), *Annales d’économie et de statistique*.<sup>16</sup>

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<sup>15</sup> “For engineers and physicists, differential equations with initial and terminal conditions are a common problem, which had been known and dealt with since a long time ... And, myself, I was an engineer,” Laffargue recalls. Boucekkine (interview) also notes that the Newton-Raphson algorithm was “somewhat banal” from the perspective of engineers and mathematicians.

<sup>16</sup> The reception of Laffargue’s method is unclear. During the 1990s, his 1990’s article is cited mainly by French economists, and in French academia and policymaking institutions this new method sparked a genuine interest (as recalled for instance by Pujol, interview). However, one cannot find, at least in writing, any early reactions from US or UK economists. Laffargue recalls though that: “I had the feeling that my work was not welcome. I had the impression the British did not like the competition brought to their own computational methods” (interview). Later

By 1990, Laffargue was able to apply his method to simulate different policy scenarios in the model he developed with Malgrange and Pujol, known as the “PLM model.”<sup>17</sup> Laffargue’s method was further refined by Raouf Boucekkine, a former ENSAE student of Malgrange. During the first two years of his PhD, Boucekkine primarily focused on examining the mathematical and computational properties of Laffargue’s method (Boucekkine, 1992; Boucekkine and Le Van, [1993] 1996; Boucekkine, 1995; Boucekkine et al., 1997). His strong mathematical background fuelled Boucekkine’s in the technical aspects of economic models. Malgrange and Laffargue encouraged Boucekkine to join CEPREMAP, emphasizing that the PLM project had resulted in numerous interesting mathematical problems for him to tackle (Boucekkine interview). He translated the original code in FORTRAN by Laffargue into GAUSS, a programming language developed in the early 1980s (later distributed as a proprietary software by the US-based company Aptech Systems). For the average user, it required less programming skills than FORTRAN. The decision to adopt GAUSS came about somewhat casually. Initially, Boucekkine worked with SAS, a widely-used statistics software in France, especially within the INSEE, and available on CEPREMAP computer terminals. Boucekkine transitioned to GAUSS upon receiving a DELL 486-D personal computer. It conveniently included the software, which was already popular among econometricians as it was geared toward numerical analysis and tuned for matrix programming. While GAUSS proved to be a powerful tool for econometric analysis, it demanded more advanced programming skills than other software like TSP (which originated at MIT and Berkeley in the late 1960s; see Renfro, 2004, 390-391 and Duarte and Sergi, this issue).

After reformulating Laffargue’s method in a more compact matrix form, Boucekkine (1995) added to the procedure a way to check the steady state stability and the uniqueness of the equilibrium path. With his CEPREMAP colleague Cuong Le Van, Boucekkine discovered, somewhat by chance, that a slight perturbation of the original dynamics led the algorithm to explode in the (rather intuitive) case where the stationary state was unstable but also when there existed a multiplicity of equilibrium paths (indeterminacy). The convergence of the algorithm after perturbation ensured the uniqueness of the equilibrium trajectory, which no other usual methods could guarantee. Finally, Boucekkine explicitly compared the properties of the new “NTB algorithm” (for Newton-Raphson-Triangularisation-Backsubstitution) with those of existing methods by Fair, Taylor and the UK macroeconometricians. This confirmed Laffargue’s early intuition that his algorithm outperformed other methods by saving computing time and capacities (Laffargue, 1990, 111; 114).

Boucekkine (interview) successfully submitted this work on algorithms as a dissertation, and was not further involved in CEPREMAP projects on *maquettes*.<sup>18</sup> This reflects a more general characteristic of the early work on the algorithm that became central to the first

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on, Laffargue’s original article was quite often cited by association with further works by Boucekkine and Juillard (e.g., Judd, 2002).

<sup>17</sup> PLM stood for “Pujol-Laffargue-Malgrange:” it did not reflect an alphabetical order or the respective contribution of the three authors, but it was explicitly conceived as a pun, referring to the Paris-Lyon-Marseille high-speed railway, under construction at the time (Pujol, interview).

<sup>18</sup> He joined Universidad Carlos III in Madrid in 1993 and quickly returned to his first affinities: mathematical economics. He then turned to vintage capital and growth models, projects dealing with delay differential equations.

version of Dynare: it was carried out by researchers who had only a passing interest in solving models with rational expectations. Likewise, Pujol primarily focused on models of the wage-price spiral type, without rational expectations when working at the DP. After his stint at the IMF (Europe Department) and subsequent return to France, he pursued other professional roles with minimal connections to macroeconomic modelling (Pujol, interview).<sup>19</sup> Of the three original contributors, Laffargue was the only one who continued to contribute to macroeconomic modelling (e.g., models such as CHARLOTTE, JULIEN, MARMOTTE), although these models were essentially deterministic and embodied perfect foresight expectations. However, he did not follow the developments of Dynare and rarely ventured into the successive versions under MATLAB. All in all, these researchers, usually theorists with programming skills, worked toward solving a problem that they knew could eventually promote the use of rational expectations models in French policy-oriented economic agencies: “our objective was not to build an operational model of the French economy, but rather, to show, through the building of a maquette, the possibility of progressing towards introducing more consistency and more rationality in the theoretical foundations of macroeconomic models of Keynesian inspiration,” Pujol, Laffargue and Malgrange (1992, 258) wrote in their presentation of the PLM maquette.<sup>20</sup> None of them however envisioned the development of such macroeconomic models themselves, or the dissemination of the algorithm, as a career path.

## 2. Toward Portability: The Development of Dynare and Its Early Dissemination (1992-2002)

### 2.1 Juillard’s Parser in Your Pocket: Floppy Disks and the Collaboration with the IMF

As he coded his algorithm in FORTRAN, Laffargue immediately realised that this was creating a portability issue, since the notation for variables was difficult to manage with large models, and it was hardly transferable to other modelling teams:

*In FORTRAN code, consumption at time  $t$ , for instance, was indexed  $X(1, it)$ , investment  $X(2, it)$ , and so far. When you had a very small model, like the [Laffargue and Malgrange, 1987], it worked well. However, with a larger model, like [Pujol et al., 1992], I have been sweating a lot. Sometimes, you made mistakes:  $X(13, ...)$  instead of  $X(14, ...)$ . People at the INSEE working on the*

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<sup>19</sup> The DP models were solved iteratively, year after year, unlike rational expectations models, which were solved in at once for all periods and appeared less intuitive and less transparent. Like the DP, the IMF was also characterized by this duality between forecasting and research. The IMF’s MULTIMOD model (*cf. infra*), for instance, incorporated the rational expectations hypothesis, but was not used for economic forecasting purposes.

<sup>20</sup> The publication of the PLM model was part of a special issue of *L’Actualité économique*, titled “Macroeconomics: Recent Developments” and edited by Malgrange and Lise Sarlas-Bronsard. The issue included several other recent developments, such as various contributions to disequilibrium theory by Malinvaud, Jacques Drèze, Guy Laroque, or Jean-Pierre Benassy. These diverse and conflicting contributions were indicative of the active competition between alternative approaches in French macroeconomics, which persisted until the 1990s, as previously mentioned and as emphasized, for instance, in Banque de France (1996)’s report on macroeconomic models used by French policymaking institutions.

*METRIC model, among others, did not code that way. They simply wrote  $C(t)$  for consumption at time  $t$ , because they already had a parser (such as Time Series Process). (Laffargue, interview)*

Laffargue discussed these portability issues with Malgrange and other colleagues at CEPREMAP. Over a 1992 lunch break, the “fantastic algorithm” that still took “pencil and paper” to be implemented caught the attention of a new CEPREMAP associate, Michel Juillard.<sup>21</sup> Juillard had no specific research interest in rational expectations macroeconomic models; his previous research was focused on structural change, using the input-output method which learned from during his training at Université de Genève (1974-1979), then at Leontief’s Institute for Economic Analysis in New York University (1981-1983), and finally at the New School for Social Research (1984-1992). But Juillard was well-versed in programming, a skill that he cultivated since high-school, and he was interested in computational methods. At the New School, he had also served for several years as the Director of the Academic Computing Center (1987-1992).

Juillard thus volunteered to help with portability concerns, hoping to build a parser that could act as a “front-end” to Boucekine’s original GAUSS code. This led to the birth of Dynare. Juillard’s first presentation of Dynare took place in 1994 during the first International Conference on Computing in Economics and Finance in Amsterdam, sponsored by the newly funded Society for Computational Economics (Juillard, interview; Juillard, 1994). The first documentation for Dynare’s original version, ‘Dynare 1.0’, was published as a CEPREMAP Working Paper in 1996, introducing it as a “generalization of Laffargue’s algorithm ... and its implementation in a Gauss program” (Juillard, 1996, 1).<sup>22</sup> This characterization highlights that Juillard original focus was to develop a pre-processor was to make Laffargue’s algorithm easier to implement (Juillard, interview).

Malgrange was interested in testing whether Laffargue’s algorithm would apply to ‘any’ model; and notably, whether this could break the “curse of dimensionality” in simulating very large-scale macroeconomic models, by significantly reducing computing time. As a test model, Malgrange chose the IMF multi-country model, MULTIMOD, which he had access to through Paul Masson, then Chief of the Economic Modelling Division at the Research Department of the International Monetary Fund (IMF). MULTIMOD first version (Mark I) had been recently developed to produce scenarios for the *World Economic Outlook* (Masson et al., 1988).<sup>23</sup> Malgrange used MULTIMOD to study the long-run properties of a dynamic model,

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<sup>21</sup> Juillard was also an associate professor of economics in Paris 8 university, since 1992. He had been brought to CEPREMAP by his collaboration with two economists associated with the research body, Pascal Petit and Robert Boyer (Juillard, interview). Thus, the collaboration between Juillard and Laffargue was again a casual encounter, since Juillard was at CEPREMAP to work on other issues: during this period, CEPREMAP’s research unit headed by Malgrange, focused on mathematical economics, was separated by the one led by Boyer, centred on regulation theory, human resources, and public economics (CEPREMAP, 1999).

<sup>22</sup> We simplified the numbering of Dynare’s versions. For an indicative chronology of different versions, see the Appendix, Table 1.

<sup>23</sup> The development of MULTIMOD was ongoing since 1988 (Masson et al. 1990) and then refined in several versions (Mark II; Masson et al. 1992; Mark III, Laxton et al. 1998). On the history of MULTIMOD and its uses in WEO forecasting, see notably Boughton (2001, chap. 5).

which he envisioned as the key step in setting the terminal conditions for simulations (Loufir and Malgrange, 1994). MULTIMOD also became the “test model” to assess how Dynare would handle large-scale models (Juillard, interview).<sup>24</sup>

This cooperation between CEPREMAP and the IMF evolved into a closer relation between Juillard and IMF economist Douglas Laxton. Around 1995, Juillard promoted Dynare through a mailing list for GAUSS users (Juillard, interview). The message caught the attention of Hope Pioro, a computer programmer from the Bank of Canada, who discussed it with her former colleague Laxton. In the early 1990s, Pioro and Laxton were developing a Newton-Raphson-based solution method for the Bank of Canada Quarterly Projection Model (QPM; Armstrong et al. (1995). The CEPREMAP and QPM methods, though developed independently, bore enough similarities to catch the interest of the duo. In the Spring of 1995, Juillard met with Laxton. Also present at the meeting was Peter Hollinger, the chief developer of TROLL. Both Hollinger and Laxton were willing to integrate the Laffargue-Boucekkine-Juillard method into TROLL: this collaboration led to the development of a TROLL new package for solving large-scale forward-looking models (Renfro, 2005, 389).

The collaboration between Laxton and Juillard led them to organize an “algorithm competition” between the Laffargue-Boucekkine-Juillard (LBJ) method and the Fair-Taylor (FT) method. They compared the computing time required by the two algorithms to achieve convergence when applied to the same model (MULTIMOD) with the same software (TROLL) and hardware (an IBM RS/6000).<sup>25</sup> Juillard et al. (1998)’s results showed that the LBJ algorithm required significantly less computing time and iterations than FT to achieve convergence after a shock was simulated. This difference even increased significantly when imposing stricter constraints to the convergence criteria and when expanding the time horizon. Specifically, FT required between 4 and 46 times more computing time, and between 10 and 100 times more iterations than LBJ (Juillard et al., 1998, Tables 5 and 10). The TROLL version of the LBJ algorithm, coded by Hollinger with the help of Juillard, was thus used in 1997 by Laxton’s team at the IMF to build a new version of MULTIMOD (Mark III; Laxton et al., 1998). This made it the first large-scale macroeconomic model in a policy-making institution to employ the Laffargue-Boucekkine-Juillard algorithm to produce simulations. It was shortly followed by QUEST II (Roger and in ’t Veldt, 1997), another multicountry model, this time developed by the European Commission’s Directorate General for Economics and Financial Affairs.

Dynare *per se* was not used at IMF to implement the LBJ algorithm in MULTIMOD. Nevertheless, Dynare’s first version in GAUSS had gradually gained popularity few places. Malgrange had adopted Dynare in his own macroeconomics teaching, especially at Université

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<sup>24</sup> TROLL is a proprietary software designed most specifically for handling large-scale macroeconomic models. It was developed in the 1960s by a team led by Edward Kuh and Mark Eisner at MIT; it was then licensed by MIT to a private corporation (Intex Solutions Inc.), which had been developing and distributing TROLL since. On the history of TROLL, see e.g. Renfro (2004, 388-390).

<sup>25</sup> The final version of the paper (Juillard et al., 1998) also tests the two algorithms into an alternative software (named SLIM) that had been developed by Paul Fisher at the ESRC Warwick Bureau (Fisher, 1990). SLIM was widespread at UK institutions of the time, especially those involved with the activities of the Bureau. This additional test was notably the result of the contribution by Peter McAdam, from University of Strathclyde, a SLIM user who had noticed the malfunctioning of MULTIMOD on SLIM (Juillard et al., 1998, page 1306-1307).

Catholique de Louvain and Universidad Carlos III of Madrid (Boucekkine, interview; Juillard, interview).<sup>26</sup> Other Louvain macroeconomists, such as David De la Croix, also embraced Dynare in their teaching and research, including for disequilibrium models (Collard, interview; De la Croix and Fagnart, 1995). The software was initially disseminated through floppy disks that CEPREMAP visitors took back to their home institutions (Juillard, interview). It was the growing ties of CEPREMAP researchers with the Society for Computational Economics that gave a strong boost to the development and dissemination of Dynare.

## **2.2 Addressing Macroeconomists' Needs: A MATLAB Version with Perturbation Methods, to Download for Free**

CEPREMAP researchers' quest for computationally tractable algorithms in the 1990s was far from isolated. As cheaper micro-computer systems became more widely available in the 1980s, these were increasingly used in econometrics but also game theory, mechanism design, static and dynamic optimization problems and to solve general equilibrium models in various fields. In 1988, Dutch economist Hans Amman, along with the help of Texas University microeconomist David Kendrick, founded the journal, *Computer Science in Economics and Management* (later renamed *Computational Economics*).<sup>27</sup> The National Science Foundation supported various workshops on computational methods, such as the one hosted by Daniel McFadden and Paul Ruud at Berkeley (Amman et al., 1996). The nascent field of "computational economics" (Kendricks, 1993) was soon institutionalized through the creation of the Society for Computational Economics (SCE) in 1994. Both Juillard and Laxton attended the SCE inaugural meeting in Austin, Texas, the following year. At the second meeting, held in June 1996 in Geneva, they presented their aforementioned work on the algorithm competition they had set up with MULTIMOD.

Their paper caught the attention of one of the leading figures in the nascent computational economics community, Stanford economist Kenneth Judd. Judd selected their paper to appear in a special issue on "Algorithms and Economic Dynamics" published in the *Journal of Economic Dynamics and Control* (Judd, 1998). At that time, Judd had been advocating for the adoption of perturbation methods in economics (Gaspar and Judd, 1997; Judd and Gu, 1997), as a tractable mean to simulate stochastic versions of dynamic macroeconomic models. In 1998, Judd and Laxton were invited by Juillard at CEPREMAP for a workshop on computational methods for solving stochastic models.<sup>28</sup> The discussions convinced Juillard that integrating perturbation methods into Dynare would be a worthy effort (Juillard, interview). Such work was then carried out in collaboration with Fabrice Collard.

Collard had obtained his PhD in macroeconomics from a research centre at Université Paris 1 specialized in macroeconomics, often referred to as "MAD" ("MACroeconomic and

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<sup>26</sup> Boucekkine had also spent some time at UCLouvain, during his PhD, to teach the students to use Laffargue's algorithm (Boucekkine, interview). The CEPREMAP-Louvain-Carlos III connection was fostered by a European research grant (SPES) obtained by Malgrange in the late 1990s (CEPREMAP, 1999).

<sup>27</sup> Both were involved in the development of GAMS (General Algebraic Modeling Systems), a software devoted to solving complex optimization problems, especially growth or computable general equilibrium models.

<sup>28</sup> "The fame of Laffargue's method came thanks to Judd. The CEPREMAP had become a Mecca for computational economics. ... At the time, when Judd said something, people will listen," Boucekkine remembers (interview).

Disequilibrium” research group). Initially contributing to the disequilibrium approach (see Plassard and Renault, 2022), MAD’s researchers (senior and junior, such as Antoine d’Autume, Frank Portier, Jean-Olivier Hairault, François Langot, and Patrick Fève, among others) had shifted focus to real business cycles (RBC) in the early 1990s, under the leadership of Collard’s supervisor Pierre-Yves Hénin (1995). Collaboration between Collard and Juillard developed naturally due to MAD’s close connections with CEPREMAP.<sup>29</sup>

Juillard and Collard set to apply perturbation methods to a model of asset pricing (Collard and Juillard, 2001a) and a Phillips curve model (Collard and Juillard, 2001b).<sup>30</sup> This collaboration with Collard convinced Juillard not just to add perturbation methods to Dynare, but also to develop a MATLAB version of the software.<sup>31</sup> Collard’s own inclination to use MATLAB stemmed from the software sharing habits among MAD students and by some path dependency. In the early 1990s, Hénin had brought back a floppy disk from a journey to the US containing a MATLAB version of the King-Plosser-Rebelo RBC model (King et al. 1988), which served as a benchmark to MAD researchers (Collard, interview). This fuelled Juillard’s recognition that many RBC-oriented applied macroeconomists, in France and worldwide, were working with MATLAB, making it a suitable choice to further the dissemination of Dynare; henceforth, endorsing that language would produce “network effects” and further the dissemination of Dynare. Indeed, Juillard had foremost the willingness to “make Dynare available to everybody, to make it something useful; and henceforth, to make Dynare available in MATLAB, as it was a widespread software for economists” (Juillard, interview). Moreover, he felt that GAUSS, initially conceived for DOS, had become less efficient, especially in its newer version developed for the Microsoft Windows operating system (for instance, the new GAUSS version lacked a debugging tool). The Linux version of GAUSS contained several incompatibilities with Dynare’s purposes (Juillard interview). This shows how historically-contingent the choice of a programming language can be: MATLAB was not merely adopted for tractability reasons (such as speed of information encoding), but for a broader mix of reasons—ranging from habits, path dependency, and collective coding culture.

By January 1999, Dynare 2.0 (integrating perturbation methods) was downloadable from [Juillard’s personal page](#) on CEPREMAP’s website. A test version had been circulating across some beta users, which included some CEPREMAP and MAD PhD students. Collard (interview) remembers that early tests raised “many questions” about how to use Dynare. This led him to write a user guide (Collard and Juillard, [2001] 2003), which provided the foundation for further Dynare manuals (Juillard, 2003a; 2003b). Collard’s original documentation was quite synthetic, and it may not have been readily accessible for those macroeconomists that were not familiar with computational issues. However, it played an important role in further

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<sup>29</sup> In addition to obvious common research interests, researchers in both institutions often had a Paris 1 and a CEPREMAP double-affiliation. For instance, Laffargue was both at CEPREMAP and a Professor at Paris 1; Hénin himself became Director of CEPREMAP in 1993. MAD’s researchers, and especially PhD students, regularly attended CEPREMAP seminars, where they benefited of insights and advice from CEPREMAP researcher. PhD students often received CEPREMAP funding for their final year (Collard, interview).

<sup>30</sup> This latter paper was closely related to the work on MULTIMOD: the Phillips curve in Collard and Juillard (2001b) is similar to the one described in Laxton et al. (1998).

<sup>31</sup> The old Dynare website also acknowledges the significant contribution of Guillaume Vandenbroucke, a PhD student of Portier at MAD, to the development of the first MATLAB version of Dynare.

disseminating Dynare. While version 1.0 of the 1990s spread mainly through interpersonal relations—i.e. people transferring floppy disks and their user’s knowledge—Dynare was now virtually accessible to anyone—at least, anyone with access to the newly created Dynare homepage, where Dynare and the user guide could be downloaded.

### **3. Dynare and the Dissemination of Bayesian-Estimated DSGE Models in Central Banks**

#### **3.1 Going Bayesian: The DSGE Approach and Dynare**

Around the time of the release of Dynare 2.0, dynamic stochastic macroeconomic modelling was coming together and stabilizing around a benchmark theoretical structure (as already foreseen by Goodfriend and King, 1997; Clarida et al., 1999), and a related label, “DSGE models”. This was not a merely academic pursuit (with Woodford, 2003, or Christiano et al., 2001 as the frontrunners), but also one driven by policy institutions. Three “DSGE” models were crafted in 2002-2003 by the IMF, the Fed Board of Governors, and the European Central Bank (ECB). In 2002, Laxton and Paolo Pesenti (a New York Fed economist on leave at the IMF) developed the Global Economy Model (GEM), the first multi-country DSGE model progressively used by IMF for building the *World Economic Outlook* scenarios (Laxton and Pesenti, 2003; Bayoumi et al., 2005).<sup>32</sup> A few blocks away from the IMF headquarter, macroeconomists at the Fed Board were also developing a new open-economy DSGE model, SIGMA (Erceg et al., 2005). Meanwhile, at the ECB, Frank Smets and Raf Wouters were completing their model (Smets and Wouters, 2003), which then became the most emblematic benchmark for DSGE models in the 2000s. Smets and Wouters’s model introduced a significant novelty, Bayesian estimation, which played a crucial role in stabilizing the DSGE approach.

The pioneering efforts of the IMF, the Fed Board, and the ECB, inspired other policymaking institutions to develop DSGE models in the following 3-4 years (for an indicative overview, see Appendix, Table 2). This spread was supported by a rapidly growing international network of modellers (such as the Central Bank Macroeconomic Modelling Workshops, started in 1998, and whose lead organizer was Laxton), as a well as a broader ‘internationalization’ of central banks’ staff economists (Claveau and Dion, 2018). This dissemination of DSGE models in academia was even faster.

Smets and Wouters (2003) canonical application of Bayesian estimation to DSGE models was one among several earlier attempts.<sup>33</sup> Bayesian estimation was perceived as a long-awaited way out from the criticisms against calibration methods, which had raged since their inception (see e.g., Summers, 1986; Ingram and Leeper, 1994; Hansen and Heckman, 1996). It also offered as solution to the computational burden of estimating rational expectations models using maximum likelihood (as originally suggested in Lucas and Sargent, 1981). While

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<sup>32</sup> Juillard was directly involved with the building of GEM, since he regularly visited the IMF Research Department during this period, providing the help with adapting the methods of Dynare to TROLL (as he did in the past for MULTIMOD Mark III, *cf. supra*).

<sup>33</sup> For a broader perspective on the Bayesian approach to econometrics, see notably Qin (2011).

Laxton had developed the IMF's GEM as a calibrated model, he believed in the benefits of Bayesian econometrics and advocated with Juillard that integrating Bayesian estimation should be the next step in Dynare's development (Juillard, interview). At the Central Bank Macroeconomic Modeling Workshops hosted by the Bank of Finland in 2002, Juillard had the opportunity to discuss with several central bank modellers involved with the development of DSGE models for institutional uses, including Wouters.

The Bank of Finland workshop led to a collaboration between Michel Juillard and Onda Kamenik from the Czech National Bank, who later joined the IMF modelling unit. With the help of computer scientist Abdeljabar Benzougar, they rewrote Dynare's original pre-processor from C to C++ (Kamenik and Juillard, 2004). This enhanced Dynare's tractability as it offered a more explicit and transparent language for advanced users, and enabled faster computation of k-th order approximations. After this workshop, the Norges Bank decided to fund the integration of Bayesian estimation into Dynare, and Juillard accepted the challenge (Juillard, interview).

The funding from Norges Bank, which was soon followed by other policy institutions assembled in the International Network for DSGE Modelling, Monetary and Fiscal Policy (DSGE-net), chaired by Juillard.<sup>34</sup> It provided a significant boost to the development of Dynare, if only because it allowed CEPREMAP to recruit researchers exclusively dedicated to the continuous improvement of the software. Among the first researchers hired were Stéphane Adjemian (2003) and Sébastien Villemot (2006), who later became official coordinators of the Dynare project in 2011. A few years earlier, Michel Juillard had taken on advisory responsibilities at the Banque de France, leading him to step back gradually from CEPREMAP and the operational management of Dynare. Adjemian's initial contribution was the development of Dynare version 3.0, which incorporated Bayesian estimation.<sup>35</sup> Building on MATLAB codes developed by DSGE modelers like Schorfheide (2000), Tao Zha (Sims and Zha, 1998), and Uhlig (1997; 1999), Adjemian successfully integrated both maximum-likelihood and Bayesian estimation techniques. Dynare 3.0 was released in 2004 (Juillard, 2004).

Just as in previous versions, the development of version 3.0 provided unforeseen opportunities for new collaborations. Marco Ratto, a researcher at the European Commission Joint Research Center, met with Juillard in the Summer 2003 to discuss the development of Monte Carlo simulation, for which he had already developed some initial stages of codes on his own (Ratto, interview). His interest in these methods was related to his work on QUEST III, a new multi-country, completed in 2003 by the European Commission Directorate General

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<sup>34</sup> The Bank of Finland, the ECB, the Banque de France, the Norges Bank, the Swiss National Bank, the Sveriges Riksbank, the Atlanta Fed, the CEPREMAP, and The Capital Group were among the members of DSGE-net. As shown in Table 2, the Norges Bank was the first central bank explicitly using and mentioning Dynare in the technical documentation of their DSGE model.

<sup>35</sup> Adjemian completed his PhD in macroeconomics at Université d'Evry in 2002, under the supervision of Jérôme Glachant. Among the members of the PhD committee were Patrick Fève, a former member of MAD, and Ferhat Mihoubi, who had studied under Malgrange at ENSAE and completed his own PhD under the supervision of Laffargue at Paris 1. Mihoubi also contributed to the development of Dynare (*cf. infra*). As a graduate student, Adjemian was not very familiar with Dynare, recalling that he had difficulty navigating the software (version 2.0) due to a lack of documentation (Adjemian, interview).

for Economics and Finance (Ratto et al., 2005). Ratto, an engineer by training, became a regular contributor to Dynare from 2003 onward (for instance through adding tools for sensitivity analysis), and a member of the “Dynare team.”

During the early 2000s, the development of Dynare indeed transitioned into a more collective endeavour. Through the collaboration of Michel Juillard, and later Stéphane Adjemian and Sébastien Villemot with various individuals and institutions interested in the development and use of Dynare, a “Dynare team” emerged. According to Juillard, the team’s collective efforts fuelled Dynare’s continuous growth throughout the 2000s and 2010s (see Appendix, Table 3 for details on the team’s expansion). In the 1990s, Dynare had evolved as a relatively independent project, with occasional and somewhat accidental collaborations among researchers like Laffargue, Boucekkine, Juillard, Laxton, and Collard. However, the early 2000s witnessed the emergence of a broader community of DSGE modelers across academia and policy-institutions coinciding with the stabilization of the DSGE approach. This community relied heavily on Dynare to facilitate their modelling practices, propose new resolution and estimation methods, and suggest additional developments. In fact, some institutions provided funding to the Dynare project, either through DSGE-net or bilateral channels, specifically for introducing new features to the software (Adjemian, interview).

Dynare’s developments in the 2000s and 2010s, particularly the enduring version 4 (2007-2022), can be characterized as incremental. Rather than introducing radical changes to the software’s foundations, new solution and estimation techniques were added to address the wider range of mathematical challenges faced by DSGE modelers. These included the Anderson-Moore algorithm for computing optimal decision rules, shock decomposition techniques, and Markov-switching SBVAR.

The team also kept improving the software’s tractability and portability: first, they improved computation times for all existing algorithms, including the original LBJ algorithm, particularly for large-scale models. Second, they introduced a broad range of options accessible through simple commands, empowering Dynare users to customize algorithms based on their specific modeling needs. Moreover, version 4 bolstered the software’s capacity to share models and results. Users could now export model equations from the .mod file to a LaTeX file, print results and data in PDF format, and customize graphic outputs, among other features. These improvements allowed for greater collaboration and dissemination of results, cementing Dynare’s status as a powerful tool for both researchers and policymakers.

Overall, Dynare’s evolution during the 2000s was driven by three types of contributors. Firstly, the Dynare team pursued their personal research interests. Secondly, modellers from academia and policymaking institutions collaborated with the Dynare team, providing code, bug fixes, and suggestions for further developments tailored to their research needs. These interactions resulted in new and long-term collaborations, some of these researchers even joining the Dynare team. Thirdly, direct demands by policymaking institutions, often accompanied by financial support, prompted specific reorientation to address policy needs. Alongside the growth of the DSGE community, another essential factor in the dissemination of Dynare was its open and free software approach.

### **3.2 Dynare as an Open and Free Software and Its Effects on Portability**

Though a GAUSS or MATLAB commercial licence was required to operate the early versions of Dynare, Juillard had always insisted that Dynare *per se* should be freely available to users—an approach later embraced by many members of the Dynare team. Consequently, the chosen license for Dynare was the General Public License (GPL), ensuring its free distribution along with its source code. Moreover, the commitment to an open software resulted in the development of versions of Dynare compatible with non-commercial mathematical software, available for both Windows and Linux operating systems. Between 2002 and 2004, Dynare 2.0 became available for Scilab—a free and open software resembling MATLAB. The development of the Scilab version was stopped shortly after the 3.0.2 release (Mancini-Griffoli, 2007, 7), since Sébastien Villemot had started developing a new version of Dynare for GNU Octave, another free and open software similar to MATLAB (the GNU Octave version was released with Dynare 4.0).

The commitment to free and open software, combined with the original design of Dynare as a pre-processor, greatly contributed to the portability of Dynare for individual research, especially in academia, and for the training of undergraduates. Virtually anyone could download Dynare for free and use it right away, either on proprietary software (MATLAB) or on a non-commercial software (Octave). Moreover, DSGEs or other models developed on Dynare could be easily shared between researchers and students as .mod files containing the model's equations, and their results thus checked and replicated.

Despite its portability, Dynare would possibly not have circulated so widely without additional initiatives that helped make Dynare accessible and relevant to its users. The user guide and related documentation grew almost exponentially, providing more extensive written guidance to newcomers (Mancini-Griffoli, 2007; Adjemian et al., 2011). An online forum allowed users to share questions and exchange knowledge. The [first version](#), running from 2006 to 2017, gathered 2730 users posting 24,571 messages (on average, six messages every day); the [second version](#) of the forum, opened in 2017, attracted nearly twice as much users (4900) and saw 61,500 messages posted. Annual summer schools were organized to train future or current Dynare users (see the list of Summer schools in the Appendix, Table 4). They were generally held in Paris and gathered 30 to 40 participants (Juillard, interview). Finally, an annual “Dynare Conference” was organized around the world, to showcase research outcomes related (but not limited) to Dynare (see Appendix, Table 5). A Dynare Working Paper Series was also launched through the Dynare website, although it only consisted of a few papers per year.

Despite its widespread use and recognition, Dynare has not been without criticism or skepticism within academia. In an interview, Harald Uhlig (2013, 66) praised Dynare as “one fantastic achievement” in “low[ering] the entry barrier” to macroeconomic modelling. But he warned: “The quality of your result depends on what you do with it, of course! Computer scientists sometimes say ‘garbage in, garbage out’.” (ibid.) Some critics have pointed out that the portability of Dynare may have inadvertently led to the perception of it as a “black-box,” where the inner workings of its computational methods, including their limitations, are no longer comprehensible to most users, particularly graduate students. Such debates surrounding Dynare can be observed in various posts about the software on the popular forum “EconJobsRumors:”

User 1: Lots of people complain that [Dynare] is like a black box, you don't know what goes in there and that is better to code from scratch all your calculations. Others say that it saves you time, just like using Stata or any other econometric software (instead of coding each step of the calculations). Any thoughts?

User 2: Dynare is the dream of any PhD student come true: No research with uncertain outcome, just fiddling around with a computer program (no need to understand the model), and getting nice output anyway.

User 3: Calling Dynare a black box is like calling Stata's `ivregress` command a black box: dynare is doing relatively basic/simple stuff. To the extent that you are fine studying approximations around a steady-state, there is no reason not to use dynare. (<https://www.econjobrumors.com/topic/what-do-you-think-about-dynare> [retrieved 25/04/22])

This was possibly one reason why Dynare was not commonly taught to graduate students. For instance, very few graduate textbooks for macroeconomics, including those focused on DSGE modelling, include training or exercises done in Dynare, while most provide some introduction to MATLAB: among the 16 most popular graduate macroeconomic textbooks identified by Courtoy et al. (2021, Table 5), only two contain a practical programming section, but only on MATLAB and Python. Some criticisms seemed to embody a different programming culture. Uhlig, for instance, argued that “Personally, I can still do certain things with my programs more easily than in Dynare. Others only use Dynare and that is just fine too, of course.” (Uhlig, 2013, 66) On “EconJobsRumors”, a PhD student asking whether he should use Dynare (“Is it a bad signal? Or no one cares?”) is confronted with two distinct and divergent attitudes:

*User 4: Dynare is fine and very well tried and tested for a particular class of models. If I work on these, I use Dynare. I don't need to build a car every time I commute to work. But it is not useful for many other macro models, and there is a danger that you really don't understand well what you are doing. Both tool obsession and sloppiness are bad for research.*

*User 5: Learn how to do it yourself using a regular numerical software like matlab. Then use dynare if you think it's easier. The problem with dynare is that many phd students get lazy and don't ever understand what they're doing. But if you avoid that and dynare can do what you want it's a good way of getting fast results without coding errors.*

(<https://www.econjobrumors.com/topic/dynare-1> [retrieved 25/04/22])

While the Dynare free software approach enhanced its portability through academia, it had more paradoxical consequences in policymaking institutions. As showed by Table 2, Dynare provided the foundation for building DSGE models in a significant number of policymaking institutions, especially after 2007. In the early 2000 however, modelers' enthusiasm for the software was compounded by executives and legal officers' uneasiness, who were rather used to cooperate with commercial software corporations (such as INTEX, distributing TROLL) and external consulting firms. Dealing with an open-source software like Dynare raised unprecedented legal questions about accountability and ‘support services’: ‘Who was responsible for Dynare?’, they asked; ‘Who should be contacted to solve problems, ask for

changes?'; 'Who should be paid for services?' (Adjemian, interview). That Dynare was developed in an institution such as CEPREMAP, with an atypical legal status, reinforced those issues.<sup>36</sup>

The problem was not merely bureaucratic. Some institutions considered that proprietary software offered better guarantees of continuity of customer service and software development, at a time models were increasingly embedded into the monetary policy-making decision process. Central banks' inflation, growth, and employment forecasts, because they formed the basis on which interest rate policies were implemented, were increasingly scrutinised by the media and the public. Could the Dynare team match commercial software teams in their commitment to maintain, debug, update their software? Consequently, institutions such as the Bank of Canada or the Fed Board kept using commercial software, such as TROLL. Other developed their own internal software, or MATLAB packages similar to Dynare: the ECB, the Czech National Bank, and the Bank of England developed, respectively, YADA, IRIS and EASE (Burgess et al., 2013).

To address the needs for 'professionalism' expressed by policymaking institutions, a condition for the software's portability there, the Dynare team had to create accountability and continuity in development and maintenance. In addition to the aforementioned constant help of users in development and debugging, this involved combining standards, organizational practices, and working routines borrowed both from academia and from the free software movement. Many of these ideas were inspired by Sébastien Villemot, who was, along with Adjemian, one of the first permanent hires of the Dynare project at CEPREMAP.

Villemot was trained in mathematics and computer science at Ecole Normale Supérieure, but chose to pursue a PhD in economics, on the Sovereign Default Risk under the supervision of French macroeconomist Daniel Cohen. He also had a strong and early interest in the free software movement, later becoming a Debian developer (Villemot, interview).<sup>37</sup> After he met Juillard as a graduate, he got involved in developing the Dynare version for GNU Octave (Villemot, interview), a collaboration that proved pivotal to reorganize the release management process: he was "the one working in the most structured manner," as his colleague Adjemian put it (interview). This resulting in a new sequence for planning, designing, scheduling, testing and deploying a new release, whereby two different branches of Dynare coexist: a stable version, (mostly) free of bugs, publicly released to users, and an unstable version on which the Dynare team is working, both hosted on Github.<sup>38</sup>

This part of the history of Dynare highlights—that, just as tractability, software portability is historically-contingent. While individual researchers, particularly in academia, and graduate students could access Dynare through simple downloading from the website and a user manual, this level of accessibility fell short in impressing policymaking institutions. To

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<sup>36</sup> Remember that, legally, CEPREMAP was neither a government affiliated agency, nor a private corporation, but something in-between, closer to a no-profit association (*cf. supra*).

<sup>37</sup> Debian is an open and free operating system, based on Linux, and developed by one of the largest communities in the free software movement.

<sup>38</sup> The version numbering system for Dynare 4 was also overhauled, adopting a more systematic three-digit classification system. This disciplined and organized development approach, championed by Villemot, also resonated with other team members like Johannes Pfeifer.

cater to their needs, the Dynare team had to adopt a more structured and 'professional' approach to development, enhancing Dynare's reputation as a reliable, continuously evolving, and transparent computational tool.

## **Conclusion**

The history of Dynare demonstrates how the concerns of France-based macroeconomists contributed to the development of a computer tool for macroeconomics. These economists, primarily associated with CEPREMAP and Université Paris 1, were interested in the interplay between theory and policy. They regarded rational expectations not merely as a theoretical curiosity, but as a genuine source of improvement for the predictive power of their models—whether rooted in disequilibrium theory, Keynesian macroeconometrics, or the new mainstream that emerged in the early 1980s. The continuous efforts to refine algorithms, enhance user-friendliness, and incorporate novel features have been instrumental in shaping the development and enrichment of Dynare. Initially supported by major French policy-making institutions such as the Commissariat général au plan and the Direction de la Prévision, funding gradually transitioned to institutions like the Banque de France and European entities like Norges Bank, the Bank of Finland, and the ECB. Throughout its developmental stages, the objectives stated by the Dynare contributors have remained consistent.

On the one hand, Dynare's development was driven by tractability issues—solving, simulating, estimating macroeconomic models. However, as our careful reconstruction of the different contexts has highlighted, this challenge was not a purely theoretical or mathematical. Instead, it was tied to the aspiration of building new kinds of macroeconomic models that could be integrated in policymaking routines (initially in France, then at the IMF, and finally in the global community of central banks). On the other hand, Dynare's development was also motivated by the ambition to facilitate the circulation of computational methods and models. This concern with portability shaped several crucial choices throughout Dynare's development, including the selection of language (MATLAB), the type of distribution license, and the organisation of both the Dynare team and its user community.

The process whereby Dynare was developed, updated and spread underscores the diverse range of contributors and contributions required for the dissemination of a class of models, in this case, those that formed the foundation for DSGE models. Beyond the prominently emphasized theoretical advances and econometric techniques by new classical and new Keynesian macroeconomists, our case study reveals that the diffusion of these models required the development of solution algorithms, a parser, computer languages, a team to maintain and update the software with new features, a funding structure, and the establishment of an institutional framework that included forums and summer schools for training economists in building, manipulating, and solving these model. For a new class of models to become dominant both inside and outside academia, it thus took not only Lucases and Sargents, but also Laffargues and Juillards.

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## Appendix

**Table 1: Versions of Dynare. An Indicative Chronology**

Version	Releases (non-exhaustive)	Year	Language(s)	Reference (manual or guide)
<b>1.0</b> Perfect foresight models; mostly based on Laffargue (1990)	1.0 (« Antique version »)	1994	GAUSS	Juillard (1996)
<b>2.0</b> Stochastic simulation of models added, based on Collard and Juillard (2001a; 2001b).	2.0.0	January 1999	MATLAB	<a href="#">Juillard's homepage</a>
	2.0.1	February 2001		Collard and Juillard ([2001] 2003)
	2.3	August 2001		
	2.5.2	January 2003	MATLAB	Juillard (2003a)
	2.6.1.1	August 2003	Scilab	Juillard (2003b)
<b>3.0</b> Estimation with maximum likelihood or Bayesian methods	3.0	2004	MATLAB Scilab	Juillard (2004)
<b>Dynare C++</b>		2004	C++	Kamenik and Juillard (2004)
<b>4.0</b> Each release of the type 4.x, introduced several additional features. For details, see <a href="#">here</a> .	4.0 Beta	2007	MATLAB	Mancini Griffoli (2007)
	4.0.0	2008	MATLAB	
	4.0.4	June 2009	MATLAB GNU Octave	
	4.1	December 2009	MATLAB	Adjemian et al. (2011)
	4.2	2011		
	4.3	2012		
	4.4	2014		
	4.5	2017		
4.6	2020	GNU Octave		
<b>5.0</b> Simulating semi-structural models; moments methods for estimation	5.0	07/01/2022		

The chronology is indicative and not exhaustive. Textual evidence (such as release announcements, user guides, etc.) is always lagging one to two years with respect to the development of a new version. The first released versions of Dynare were not always numbered in a consistent way (hence the discontinuities in this chronology).

**Table 2: Use of Dynare by Policymaking Institutions**

<b>Institution</b>	<b>Model Name</b>	<b>Year</b>	<b>References</b>	<b>Software or Package mentioned in documentation</b>
European Central Bank	NAWM	2003	Smets and Wouters (2003); Christoffel et al. (2008)	TROLL, YADA, and <b>Dynare</b>
International Monetary Fund	GEM	2003	Laxton and Pesenti (2003)	TROLL
Federal Reserve Board	SIGMA	2005	Erceg et al. (2005)	TROLL
Bank of England	BEQM	2005	Harrison et al. (2005); Harrison and Oomen (2010)	[Software specific to the Bank of England]
Czech National Bank	New Model or G3	2005	Beneš et al. (2005)	TROLL/IRIS
European Commission	QUEST	2005	Ratto and Röger (2005); Ratto et al. (2009)	TROLL and <b>Dynare</b>
International Monetary Fund	GFM	2006	Botman et al. (2006)	TROLL
Bank of Canada	ToTEM	2006	Murchison and Rennison (2006)	TROLL
Norges Bank	NEMO	2006	Brubakk et al. (2006); Brubakk and Sveen (2009)	<b>Dynare</b>
Bank of Finland	AINO	2006	Kilponen and Ripatti (2006)	TROLL
Banco de España	BEMOD	2006	Andrés et al. (2006)	NA
Banco central de Chile	MAS	2006	Medina and Soto (2006)	NA
International Monetary Fund	GIFM	2007	Kumhof et al. (2010)	TROLL and <b>Dynare</b>
Sveriges Riksbank (Sweden)	RAMSES	2007	Adolfson et al. (2007)	NA
Bank of Thailand	BOT-DSGE	2007	Tanboon (2008)	IRIS
Swiss National Bank	DSGE-CH	2007	Cuche-Curti et al. (2009)	<b>Dynare</b>
French Ministry for the Economy and Finance	Omega3	2007	Carton and Guyon (2007)	NA

Banco Central de Reserva del Perú	MEGA-D	2008	Castillo et al. (2009)	<b>Dynare</b>
Banco Central do Brasil	SAMBA	2008		<b>Dynare</b>
Banco de la Republica (Colombia)	PATACON	2008	González et al. (2011)	<b>Dynare</b>
Reserve Bank of Australia		2008	Jääskelä and Nimark (2008)	None
Ministère de l'économie du Luxembourg	LSM	2008	Deak et al. (2011)	NA
Banco de Portugal	PESSOA	2008	Almeida et al. (2008; 2013)	NA
South Africa Reserve Bank		2008		<b>Dynare</b>
Reserve Bank of New Zeland	KITT	2009	Lees (2009)	IRIS
Banco de España	MEDEA	2009	Burriel et al. (2010)	<b>Dynare</b>
Czech Ministry of Finance	HUBERT	2009	Štork et al. (2009);	NA
Banque centrale du Luxembourg	LOLA	2009	Pierrard and Sneessens (2009); Marchiori and Pierrard (2012)	NA
Bangko Sentral ng Pilipinas		2009	McNelis and Glindro (2009)	<b>Dynare</b>
Federal Reserve Board	EDO	2010	Chung et al. (2010)	NA
Bank of Japan	M-JEM	2010	Fueki et al. (2010)	<b>Dynare</b>
Sedlabanki Islands		2010	Seneca (2010)	<b>Dynare</b>
European Central Bank	EAGLE	2010	Gomes et al. (2010)	TROLL and <b>Dynare</b>
Bank of England	COMPASS	2011	Burgess et al. (2013)	MAPS (specific to the Bank of England)
OECD		2012	Cacciatore et al. 2012	NA
Federal Reserve Bank of Chicago		2012	Brave et al. (2012)	MATLAB
Bank of Israel	MOISE	2012	Argov et al. (2012)	<b>Dynare</b>
Banco de España and Deutsche Bundesbank	FiMOD	2012	Stähler and Thomas (2012)	NA

Federal Reserve Bank of New York		2013	Del Negro et al. (2015)	MATLAB; Julia
Sveriges Riksbank	RAMSES II	2013	Adolfson et al. (2013)	NA
Bank of Canada	ToTEM II	2013	Dorich et al. (2013)	NA
International Monetary Fund	MAPMOD	2014	Benes et al. (2014)	NA
Swiss National Bank		2014	Rudolf and Zurlind (2014)	NA
NCAER (India)		2015	Banerjee et al. (2015)	NA
Reserve Bank of New Zealand	NZSIM	2015	Kamber et al. (2015)	NA
Norges Bank	NEMO II	2017	Gerdrup et al. (2017)	NA

The list of DSGE models is not exhaustive. It is based on work by Sergi (2020) and Yagihashi (2020).

**Table 3: The Dynare Team**

<b>Year(s)</b>	<b>Team Members</b> (alphabetical order)
1994-1997	M. Juillard
1997-2001	M. Juillard, F. Collard, G. Vandenbroucke
2003-2007	M. Juillard, S. Adjemian, A. Benzougar
2007-2010	S. Adjemian, Houtan Bastani, M. Juillard, Ferhat Mihoubi, George Perendia, M. Ratto and S. Villemot
2011	S. Adjemian, H. Bastani, M. Juillard, Frédéric Karamé, Junior Maih, F. Mihoubi G. Perendia, M. Ratto, and S. Villemot
2013	S. Adjemian, H. Bastani, M. Juillard, F. Karamé, J. Maih, F. Mihoubi, G. Perendia, Johannes Pfeifer, M. Ratto, and S. Villemot
2019	S. Adjemian, H. Bastani, M. Juillard, F. Karamé, Dóra Kocsis, J. Maih, F. Mihoubi, G. Perendia, J. Pfeifer, M. Ratto, and S. Villemot
2020-2021	S. Adjémian, H. Bastani, M. Juillard, Sumudu Kankanamge, F. Karamé, J. Maih, Selma Malmberg, F. Mihoubi, Willi Mutschler, J. Pfeiffer, M. Ratto, N. Rion, S. Villemot

**Table 4: Dynare Summer Schools**

<b>Event name</b>	<b>Date</b>	<b>Place</b>	<b>Instructors and Keynote speakers</b>
Dynare Summer School (“edition 0”)	2004	Paris (CEPREMAP)	
“Workshop on learning and monetary policy”	October 17-20 2005	Paris (Maison des Sciences)	M. Juillard, T. Sargent, S. Adjemian, T. Zha

		économiques, Université Paris 1)	
Dynare Summer School ( <a href="#">1<sup>st</sup> edition</a> )	June 30 <sup>th</sup> - July 4 <sup>th</sup> 2008	Paris (Maison des Sciences économiques, Université Paris 1)	M. Juillard, W. den Haan, S. Adjemian, S. Villemot
Dynare Summer School ( <a href="#">2<sup>nd</sup> edition</a> )	June 22-26 2009	Paris (Paris School of Economics)	NA
Dynare Summer School <a href="#">2010</a>	June 28 <sup>th</sup> – July 2 2010	Paris (Banque de France)	S. Adjémian, Roger Farmer, M. Juillard, F. Mihoubi, S. Villemot
Dynare Summer School <a href="#">2011</a>	June 20-24 2011	Paris	S. Adjemian, M. Juillard, F. Mihoubi, S. Villemot, Ester Faia, Marek Jarocinski, J. Pearlman, M. Ratto, Sebastian Schmidt
Dynare Summer School <a href="#">2012</a>	June 18-22 2012	Paris	S. Adjemian, M. Juillard, F. Mihoubi, S. Villemot, M. Ratto
Dynare Summer School <a href="#">2013</a>	June 24-28 2013	Paris	S. Adjemian, M. Juillard, F. Mihoubi, M. Ratto, S. Villemot, T. Zha
Dynare Summer School <a href="#">2014</a>	June 9-13, 2014	Paris	S. Adjemian, H. Bastani, M. Juillard, F. Karamé, J. Maih, M. Ratto, S. Villemot
Dynare Summer School <a href="#">2015</a>	June 8-12 2015	Paris	S. Adjemian, H. Bastani, M. Juillard, F. Karamé, M. Ratto, S. Villemot
Dynare Summer School <a href="#">2016</a>	June 6-10 2016	Le Mans (Université du Maine)	S. Adjemian, M. Juillard, F. Karamé, J. Pfeifer, M. Ratto, S. Villemot
Dynare Summer School <a href="#">2017</a>	June 12-16 2017	Paris (Université Paris Est Créteil)	S. Adjemian, Thomas Brand, M. Juillard, F. Karamé, M. Ratto, Xavier Ragot, S. Villemot
Dynare Summer School <a href="#">2018</a>	June 10-15 2018	Paris (Banque de France)	S. Adjemian, T. Brand, M. Juillard, F. Karamé, M. Ratto, S. Villemot
Dynare Summer School <a href="#">2019</a>	June 3-7 2019	Paris (ENS, Jourdan)	S. Adjemian, H. Bastani, T. Brand, M. Juillard, F. Karamé, M. Ratto, S. Villemot, Thomas Winberry

**Table 5: Dynare Conferences**

<b>Event Name</b>	<b>Date</b>	<b>Place</b>	<b>Keynote speakers</b>	<b>Organizers</b>
<a href="#">“Quantitative Evaluation of Stabilization Policies”</a>	September 23-24 2005	New York (Italian Academy for Advanced Studies in America)	Panel on “The role of quantitative models in policymaking”  Speakers: Jarle Berge (Norges Bank), Spencer Dale (Bank of England), Marvin Goodfriend (Carnegie Mellon University), and Douglas Laxton (International Monetary Fund)	Federal Reserve Bank of New York, the Program for Economic Research at Columbia University, and the Dynare Project of CEPREMAP.  Woodford, Pesenti (NY Fed), and Juillard
<a href="#">“The 2006 Dynare Conference”</a>	September 4-5 2006	Université Paris 1 Panthéon-Sorbonne	John Geweke and Chris Sims	Organized with the support of CEPREMAP, EUREQUA and Paris-Jourdan Sciences Economiques.
<a href="#">3<sup>rd</sup> Dynare Conference</a>	September 10-11 2007	Paris (Paris School of Economics) – Initially planned in Lausanne (HEC)	K. Adam J. Fernandez–Villaverde	E. Jondeau (HEC Lausanne), M. Juillard and F. Pelgrin (HEC Lausanne)
<a href="#">4<sup>th</sup> Dynare Conference</a>	September 4-5 2008	Boston (Boston Fed)	Jesper Lindé and Malin Adolfson (Sveriges Riksbank)  Frank Schorfheide (Univ. of Pennsylvania) and S. Borağan Aruoba (Univ of Maryland)	Jeff Fuhrer (Federal Reserve Bank of Boston) Michel Juillard (Bank of France) Scott Schuh (Federal Reserve Bank of Boston)
<a href="#">5<sup>th</sup> Dynare Conference</a>	August 31-June 1 <sup>st</sup> 2009	Oslo (Norges Bank)	Andrew Levin, Tao Zha	Norges Bank, DSGE-net, and the Dynare Project at CEPREMAP
<a href="#">6<sup>th</sup> Dynare Conference</a>	June 3-4 2010	Helsinki (Bank of Finland)	Fabio Canova Thomas Sargent	Michel Juillard (Bank of France and CEPREMAP), Juha

				Kilponen (ECB and Bank of Finland), Antti Ripatti (Bank of Finland) and Jouko Vilmunen (Bank of Finland)
<a href="#">7<sup>th</sup> Dynare Conference</a>	September 9-10, 2011	Atlanta (Atlanta Fed)	Lars Hansen and Giorgio Primiceri	Michel Juillard (Bank of France), Daniel Waggoner (Federal Reserve Bank of Atlanta) and Tao Zha (Federal Reserve Board of Atlanta).
<a href="#">8<sup>th</sup> Dynare Conference</a>	September 20-21 2012	Zürich (Swiss National Bank)	Lawrence Christiano and Juno Mairi (IMF)	Nicolas Cuche-Curti (Swiss National Bank), Alain Gabler (Swiss National Bank), Michel Juillard (Bank of France)
<a href="#">9<sup>th</sup> Dynare Conference</a>	October 28-29 2013	Shanghai University of Finance and Economics (SUFE)	Chris Sims (Princeton University) and Oreste Tristani (European Central Bank)	Kevin Huang (Vanderbilt University) Michel Juillard (Bank of France) Tao Zha (Federal Reserve Bank of Atlanta).  Local organizers: Guan Gong (SUFE) Fang Wang (SUFE)
<a href="#">10<sup>th</sup> Dynare Conference</a>	September 18-19, 2014	Paris (Banque de France)	Collard and Alejandro Justiniano (Fed Chicago)	NA
<a href="#">11<sup>th</sup> Dynare Conference</a>	September 28-29, 2015	Brussel (National Bank of Belgium)	Gianni Amisano (Federal Reserve Board) and Harald Uhlig (University of Chicago)	Pelin Ilbas (National Bank of Belgium), Michel Juillard (Banque de France) and Raf Wouters (National Bank of Belgium).
<a href="#">12<sup>th</sup> Dynare Conference</a>	September 29-30 2016	Rome (Banca d'Italia)	Pierpaolo Benigno (LUISS Guido Carli University and EIEF) and Raf Wouters (National Bank of Belgium)	Andrea Gerali (Banca d'Italia), Michel Juillard (Banque de France), Alessandro Notarpietro (Banca

				d'Italia), and Massimiliano Pisani (Banca d'Italia).
<a href="#">13<sup>th</sup> Dynare Conference</a>	October 28-29 2017	University of Tokyo	Nobuhiro Kiyotaki (Princeton University) and Tack Yun (Seoul National University)	Kosuke Aoki (University of Tokyo), Ippei Fujiwara (Keio University and ANU), Tomoyuki Nakajima (University of Tokyo), Stéphane Adjemian (CEPREMAP and Université du Mans), Michel Juillard (Banque de France).
<a href="#">14<sup>th</sup> Dynare Conference</a>	July 5-6, 2018	European Central Bank in Frankfurt	Stephanie Schmitt-Grohé (Columbia University) and Peter Karadi (ECB)	Ivan Jaccard (ECB), Anton Nakov (ECB), Sebastien Schmidt (ECB), Michel Juillard (Banque de France).
<a href="#">15<sup>th</sup> Dynare Conference</a>	September 9-10 2019	HEC Lausanne	Morten Ravn and Gianluca Violante	Stéphane Adjemian (Université du Mans), Philippe Bacchetta (Université de Lausanne), Kenza Benhima (Université de Lausanne), Florin Bilbiie (Université de Lausanne), Michel Juillard (Banque de France), Simon Scheidegger (Université de Lausanne)