Finite State Machine Modelling of the Macro-Economy

João Marques Silva and José Azevedo Pereira
Instituto Universitário de Lisboa (ISCTE-IUL)Lisbon, Portugal
Email: joao.silva@iscte.pt; jpereira@iseg.ulisboa.pt

***Abstract*—In this paper we model macro-economic policies with a Finite State Machine (FSM). The FSM is made of several states and transitions between states, in which a state is modelled by a set of conditions. The allowed transitions between states must be also be defined, in order to complete the model. In this paper we analyze how to use a FSM in order to model macroeconomic decision, where each state represents a set of economic decisions. Together with some pre-defined initial conditions, these adapted FSM models are analyzed in order for us to study what sequence of decisions yield the best results for pre-determined end-goals, based on the FSM's possibilities. The final model shows what policies must be followed, and by what order, in order to maximize results, yielding some interesting conclusions.**

***Index Terms*—finite state machines, macro economy, modelling, politics**

I. Introduction

Economic models are complex, since a country's economy is dependent on politics, people's reactions to politics, resource limitations, environmental and geographical constraints, institutional and legal requirements, other countries' interactions, etc. Put it simply, a country's economy is dependent on so many aspects that makes it very hard to predict.

Since the classical model (that focused on the equilibrium between supply and demand for labor) [1] in 1776, we focused on the Keynesian Models (1936-1969), that started as a vastly oversimplified view of the economy, constructing an equilibrium without referring to the labor market, showing that an economy can be in equilibrium without having full employment [2-3]. The Keynesian model is then expanded to the IS / LM (Interest Saving – Liquidity Money Supply) model, focusing on long-term and short-term interest rates. Income and the interest rate are variables used to achieve equilibrium. The model was updated from a closed to an open economy with the Balance of Payments (BoP) in the Mundell-Fleming model (also known as IS-LM BoP model) [4-5]. In 1970 a "new" classical model was introduced, shifting attention from nominal interest rates back to the real factores of production that dominated the original classical model [6-7]. After the recession in 1982, the debate about the real effects of nominal monetary policy was reopened, and the IS/MP (Monetary Policy) model was created [8], addressing a perceived shortcoming of the IS-LM model, replacing the price level with the inflation rate and by replacing the nominal interest rate with the real interest rate.

More recently, some new economics models have come into play [9-10], but all differ from each other and have different purposes. In this paper, we devised a simple model, based on Finite State Machines (FSM). This form of representation is disruptive on economic models, and focuses on the economy's evolution based on a pre-determined set of (political) decisions, and is used to determine which set of decisions must be taken in order to maximize a chosen variable (Gross Domestic Product, for example).

The paper is structured as follows: in section II we introduce Finite State Machines and in section III we build a macroeconomic model based on Finite State Machines. Section IV portrays some results that stem from different transitions (decisions) in the model, and in section V some conclusions are drawn.

II. Finite State Machines

A Finite-State Machine (FSM) is a mathematical model used to represent different states and the transitions between them. The theory of FSM is explained in [11], and stemmed from work in [12], with the original presentation of regular expressions and their connection with machines. Particularization of the machines with output that were a function of state and input [13] and a function of solely the state [14] were drawn by G.H. Mealy (Mealy Machines) and Edward F. Moore (Moore Machines) respectively.

In this paper we make use of Mealy machines (outputs dependent on both state and input) and model macro-economic policies by different states, studying the effect of different sets of transitions between them. The policies can be user-defined, and the number of states is unlimited, though for simplicity and clarity we suggest a maximum of 4. This model will serve as a basis for studying the best transitions between states to obtain certain macro-economic results, and to predict the economy's evolution in future works.

Manuscript received June 18, 2017; revised August 31, 2017

doi: 10.18178/joams.5.5.333-337

III. Economic Model Based on FSM

A 4-state machine was devised, where each state represents one of four different kinds of political decisions. The variables that were selected to model each state can be changed; however, the used values were chosen to serve as a practical (and somewhat realistic) example. With the FSM mechanism, we can model a country's economy (or any economy, for that matter) by a stochastic process, and use it to forecast economic activity and/or propose changes in economic policies.

This model provides an argumentative framework that can be discussed and tested for different scenarios. Since it is a simple representation of the complexities of the economy, its results will serve as approximate representations of the economy, highlighting key relationships between some variables.

The model must be adjusted for accuracy by cross-checking with historical data and fine-tuning the characteristics of each state. This should be an iterative process until all states are good representations of the reality. The used aggregate variables can be modified and validated by econometrics. The model is built to sustain deterministic chaos, caused by sudden change in policies and portrayed by certain transitions between states. Future works can portray those changes by probabilities linked to state transitions.

The policies of each state will influence its variables, which are the same for all states. The influences will reference overall variables that we defined as (these values were used as an example; they can be changed):

Z (Discount rate)	3%
Tax level	75%
UF (Unfairness Factor)	10
Number of workers	600

The model that was used as an example is portrayed in Fig.1:

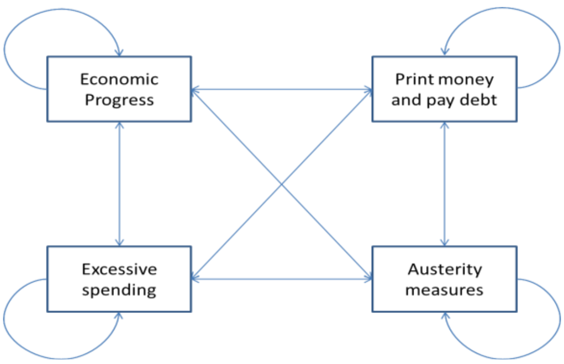

Figure 1. 4 state FSM model with all possible transitions

Each of the four states represents certain policies, with the corresponding variables change. We assume that once a transition has been made, things will evolve according to the state's variable functions during one period. Since the states are connected in a full-mesh, any state can evolve to any other state, including itself. The state's policies are as follows (depicted in Table I):

After each transition, the state's variables are updated. Once changed, the variables they are assumed fixed throughout the whole period (year, in this case), and used for the "throughout the year calculations" of the following variables:

Expenses = Expense coefficient x Total money

Tax = Tax level*(40% total money + 60% mean wages x number workers x (1- unemployment)) x (1 - Tax evasion)

Debt Interest= Z times debt

Cost each unit = Total money / Production

Yearly Profit = Taxes collected - Expenses - Debt interest

Political value = 5*Mean Wage/ Cost per Unit + 1/(10 x Unemployment)

Economic value =Production * (Political Value/2 + (Exports/Imports) + expected(Taxes collected/Expenses)-Debt/Total money+1/(Debt spread*10))

TABLE I. Defining Conditions of Each State

	Scenario A - no debt payment	Scenario B - with total debt payment	Scenario C - repositioning of just wages	Scenario D - Austerity measures	Boundaries
Total money	+ Z%	total money plus debt	=	=	>0
Production	+ Z%	=	=	- 2Z	>0
Mean wage	+ Z%	Decreases UFxZ compared to fair wage	Total money x 60% / number workers	- 2Z	>0
Expense coefficient	- Z% for 3x in a row, then +2Z	=	=	- 4Z	(min,max 20%,90%)
Tax evasion	=	+25%	-10%	+10%	(min,max 5%,90%)
Unemployment	-1% for 3x in a row, then =	- 3%	+ 5%	+ 2%	(min,max 2%,50%)
Debt spread	-1%	+ 15%	+ 3%	- 2Z	(min,max 1%,30%)
Imports	=	-UFxZ	Increases by wage increase %	- 2Z	(min 0)
Exports	=	+	+/=	+	(min 0)
Exchange Rate	=	coin	=	=	>0

Note that both the political and economic value are values only useful for simulation purposes. Some memory effect will be considered for the "economic progress" state (scenario A), in which remaining in such state for after 3 periods will have a different effect in its defining variables. Such is the case for Scenario A. namely for the expense coefficient and unemployment. It is assumed that the first 3 consecutive times each value will decrease (Z% and 1% respectively), and will then either rise or stay constant after the fourth consecutive year. The authors decided that scenario A wouldn't remain perfect *ad eternum*, and thus admitted that expenses would break loose at the 4th consecutive year (election effect), while unemployment would stop descending.

Scenario B assumes that the government will "print money" to pay off the whole of its debt, and suffer some consequences with the debt spread and tax evasion. It also introduces the notion of "fair wage", which basically is equal to the proportion of total money increase; Fair wage = initial wage x (new total money/ total money previous year), which means that the fair wage wouldn't render any loss in buying power.

Scenario C assumes that the policies for the current year will center on the repositioning of just wages (re-instate the same purchasing power as in the initial state), causing a positive effect on tax evasion, but increasing both the unemployment rate and debt spread. Scenario D, on the other hand, assumes a scenario of austerity, which reduces the expense coefficient and debt spread, but has negative effects on the economy.

The exports of each state are calculated from the following formulas:

Exports = Production - National consumption

National consumption = Total consumption - imports

Total consumption = Production x (Mean Wage/ Cost of each unit)

Cost of each unit = Production - Total money

IV. Results

TABLE II. Initial Conditions for Simulator

Variable	Value	units	Goal
Total money	1 000 000	currency	maximize
Production	1 000	units	maximize
Mean wage	1 000	currency	maximize
Debt	1 000 000	currency	minimize
Expense coefficient	40%		minimize
Tax evasion	15%		minimize
Unemployment	12%		minimize
Debt spread	1%		minimize
Imports	100	units	minimize
Exports	100	units	maximize
Exchange Rate	1	domestic/foreign	maximize

With all the rules explained, we are now in the condition of running the model. A simulator was built, that runs all possible combinations of the model for a number of iterations (each iterations represents a year). Having all results from all possible combinations, we can assess which state transitions yield the best values (maximum or minimum, depending on the case) for each variable. Note that we don't deal with transition probabilities (yet), rather we will just study what transitional sequences lead to specific results, and analyse those transitions.

Starting with the initial conditions depicted in Table I, where the goal for each variable is detailed:

We can run the simulator for all combinations in order to obtain the best transition sequences for all iterations (in this case, years); this in portrayed in Table III. Looking at the table, we can see that the sequences can suffer some changes between years, meaning that the best transition sequence to maximize/minimize a variable on year x might be significantly different than for year x+1. Looking at the case of Debt (here, the smaller the Debt, the better; negative debt represents a surplus), we have that while the best transition sequence for 3 years is 112 (representing a transition to state 1 for the first and second year, and a transition to state 2 at the third year), the best transition to minimize debt for 4 years is totally different (4321) – one could expect that the transitions for the first 3 years would remain the same (112), but this proves it different.

In Table IV, we have the yearly evolution of the values for the best transition state of 10 years (the rightmost column of Table III). Looking at the debt for reference again, we can see that the transition for year=2 was 2, which means cancelling off the debt (and thus the debt value for that value is 0). The value evolves to a negative value (meaning that our country has loaned money to someone else and is getting interest on it). Some values of interest for governments would be the political value and/or the economic value; each of these values have different transition sequences to maximize them, and it is interesting to see that, according to our model, both value rise and fall across the years in order to obtain their highest value in year 10. This simple model thus summarises one big economic and universal truth; sometimes we need to take some steps back in order to move forward. Since in politics we have waves of 4-5 years mandates, we can see by this examples that governments would only be interested in taking actions to maximize some variables on a shorter term.

TABLE III. Best Transition Sequences for Each Variable, according to Number of Iterations (Years)

	Iteration (Year)									
Variables	1	2	3	4	5	6	7	8	9	10
Total money	2	22	222	2222	22222	222222	2222222	22222222	222222222	2222222222
Production	1	11	111	1111	11111	111111	1111111	11111111	111111111	1111111111
Mean wage	2	23	223	2232	22232	222232	2222232	22222232	222222232	2222222232
Debt	2	12	112	4321	43231	432331	4323331	43233311	432333131	4233331311
Expense coefficient	4	44	144	1114	11124	111144	1111144	11111244	111111444	1111111444
Tax evasion	3	13	113	1113	11113	111113	1111113	11111113	111111113	1111111113
Unemployment	2	22	222	2221	11222	122111	1121211	11221111	112211111	1112124111
Debt spread	1	11	111	1111	11111	111111	1111111	11111111	111111111	1111111111
Imports	2	22	222	2222	22222	222222	2222222	22222222	222222222	2222222222
Exports	4	44	444	4242	22222	222222	2222222	22222222	222222222	2222222222
Exchange Rate	1	11	111	1111	11111	111111	4323332	43233332	412133332	2433133412
Political Value	1	11	222	1222	11222	111212	1112121	11112121	111112121	1122231211
Economic Value	1	11	111	1111	14111	114111	1113111	11131111	111311111	1113111111

Our model can be changed both in the initial conditions, number of states, state rules and possibilities of transitions. So being, another simulation was run, but this time we disallowed recursion on states 2 and 3; meaning that when on state 2 or state 3, we can't have a transition to the same state on the following year (Fig. 2).

TABLE IV. YEARLY EVOLUTION OF EACH VARIABLE, FOR THE BEST TRANSITION STATE OF 10 YEARS

	Iteration (Year)									
Variables	1	2	3	4	5	6	7	8	9	10
Total money	1983040	2153280	2630102	3551331	5228332	8292383	1,4E+07	2,5E+07	47519263	94017922
Production	1030	1061	1093	1126	1159	1194	1230	1267	1305	1344
Mean wage	1805	1783	1982	2435	3263	4709	7253	11835	25168	72369
Debt	983040	0	52097	-5487	-158631	-432380	-868145	-2E+06	-2396989	-3639682
Expense coefficient	0,37	0,34	0,31	0,37	0,43	0,49	0,55	0,43	0,31	0,2
Tax evasion	0,15	0,15	0,15	0,15	0,15	0,15	0,15	0,15	0,15	0,05
Unemployment	0,11	0,1	0,09	0,06	0,05	0,02	0,04	0,03	0,02	0,01
Debt spread	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Imports	91	83	75	69	62	57	52	47	43	39
Exports	181	255	322	383	438	489	535	577	615	650
Exchange Rate	0,50428	0,504276263	0,5042763	0,50428	0,504276	0,50428	0,50428	0,50428	0,504276	50360,2653
Political Value	6	6	6	7	9	7	7	8	10	15
Economic Value	14767	15521	16422	7183	8841	11660	18801	19223	19744	20397

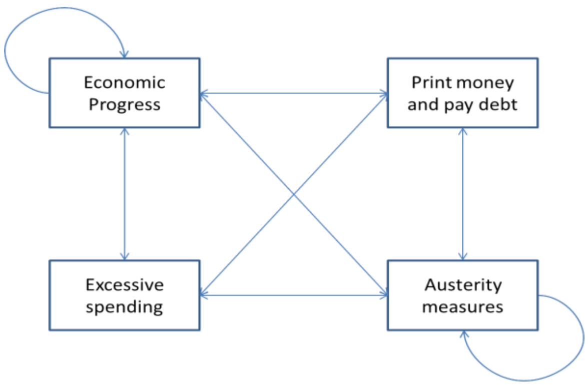

Figure 2. 4 state FSM model with some transition restrictions

With this restriction, we obtained the new tables, Table V and Table VI, with significantly different transitions, and, as expected, some final values that were either the same or a bit worse (higher or lower casuistically). Looking at the political value as an example, we see that the final value is still 15, with transitions moving from (1122231211) to (2121231211), which is substantially different, but yielding a similar result. A well-tuned model could help governors decide on their strategy according to existing constraints, and have a means of communicating the message and set their objectives.

The results for the FSM model without recursion on states 2 and 3 are as follows (portrayed in Table V and Table VI):

TABLE V. BEST TRANSITION SEQUENCES FOR EACH VARIABLE, ACCORDING TO NUMBER OF ITERATIONS (YEARS), WITHOUT RECURSION ON STATES 2 AND 3

	Iteration (Year)									
Variables	1	2	3	4	5	6	7	8	9	10
Total money	2	21	212	2112	21212	212112	2121212	21212112	212121212	2121212112
Production	1	11	111	1111	11111	111111	1111111	11111111	111111111	1111111111
Mean wage	2	23	232	2123	21232	212132	2121232	21212132	212121232	2121212132
Debt	2	12	112	4321	43231	432311	4323131	43231311	432313131	4323131311
Expense coefficient	4	44	144	1114	11124	111144	1111144	11111244	111111444	1111111444
Tax evasion	3	13	113	1113	11113	111113	1111113	11111113	111111113	1111111113
Unemployment	2	12	212	2121	21212	212111	1121211	12121111	121211111	1112124111
Debt spread	1	11	111	1111	11111	111111	1111111	11111111	111111111	1111111111
Imports	2	24	242	2424	24242	242424	2424242	24242442	242424242	2424242424
Exports	4	44	444	4242	24242	244242	2424242	42424242	242424242	2124244242
Exchange Rate	1	11	111	1111	11111	111111	4311132	43231312	413231312	3213134342
Political Value	1	11	111	1212	21212	111212	1112121	11112121	111112121	2121231211
Economic Value	1	11	111	1111	14111	114111	1113111	11131111	111311111	1113111111

TABLE VI. YEARLY EVOLUTION OF EACH VARIABLE, FOR THE BEST TRANSITION STATE OF 10 YEARS, WITHOUT RECURSION ON STATES 2 AND 3

	Iteration (Year)									
Variables	1	2	3	4	5	6	7	8	9	10
Total money	1983040	2042531	2354474	2425108	3405366	3507527	5723543	5895249	6072107	14531605
Production	1030	1061	1093	1126	1159	1194	1230	1267	1305	1344
Mean wage	1805	1859	1950	2008	2566	2643	3925	4043	5895	13023
Debt	983040	913661	0	-43298	-198206	-453856	-860823	-1439579	-2285953	-3412309
Expense coefficient	0,37	0,34	0,31	0,37	0,43	0,49	0,55	0,43	0,31	0,2
Tax evasion	0,15	0,15	0,15	0,15	0,15	0,15	0,15	0,15	0,15	0,05
Unemployment	0,11	0,1	0,09	0,06	0,05	0,02	0,04	0,03	0,02	0,01
Debt spread	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Imports	91	86	78	73	67	63	57	54	49	46
Exports	181	181	234	316	375	425	460	496	511	538
Exchange Rate	1	0,51178178	0,51178178	0,51178178	0,51178178	0,5117818	0,5117818	0,5117818	0,51178178	16738,227
Political Value	6	6	6	7	9	7	7	8	10	15
Economic Value	14767	15521	16422	7183	8841	11660	18801	19223	19744	20397

V. CONCLUSION

This work modelled different economic evolutions due to different political decisions, supported by the application of a Finite State Machines (FSM). In fact, political decisions are focused on maintaining popularity first, and insuring high economic value second. We demonstrated that the economy's evolution may not always follow the best long-term result, being merely centered on periodic election cycles – this being, the key question that society must place as a whole is how to ensure that economic plans are made on the long-term while maintaining the democratic degree of freedom – this or a similar tool must be used by future decision-makers in order to ensure the best long-term decisions and results.

In future works, a Markov mode (a stochastic model used to model randomly changing systems where it is assumed that future states depend only on the current state not on the events that occurred before it) will be assumed in order to account for uncertainty.

ACKNOWLEDGE

We gratefully acknowledge financial support from FCT- Fundação para a Ciencia e Tecnologia (Portugal), national funding through research grant (UID/SOC/04521/2013).

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João Carlos. M. Silva received the BSc and MSc degree for Aerospace Engineering from Instituto Superior Técnico (IST) – Lisbon Technical University, (1995-2000). From 2000-2002 he worked as a business consultant in strategic management in McKinsey&Company. From 2002 to 2006 he undertook his PhD in telecommunications at IST, integrated in 3 EU projects (Seacorn, B-Bone e C-Mobile), having been the representative of the university. Since 2006, he has been working on computer networks, as an assistant professor in Instituto Superior das Ciências do Trabalho e da Empresa (ISCTE). Recently, he finished his MBA at ISEG (Instituto Superior de Economia e Gestão), and aims to work on technological management in the near future. Email: joao.silva@iscte.pt

José Azevedo Pereira is a full Professor of Finance, at Universidade de Lisboa, ISEG - Instituto Superior de Economia e Gestão. He holds a PhD from the Manchester Business School and an MBA, from ISEG. Besides his academic career he has held top executive positions in several companies. During seven years he led the Portuguese Tax and Customs Authority, where he was Director-General and Chairman of the Board. Email: jpereira@iseg.utl.pt