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Minimum Wage Policy: A Markov Decision Approach

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Abstract: In this paper, the Markov decision process with multi-objective Q-learning algorithm is proposed for setting minimum wage. The policy objectives are maximizing economic growth and income equality and minimizing unemployment. The indicators based on ILO 131 are selected to support these objectives. The states which are minimum wage rate, actions (% of rising), rewards based on OLS (Ordinary Least Square), $\ddot{Q}$-values and $\overline{SQ}$-values are calculated to select appropriate action. Policy makers can define the weight vectors of objectives and define % of rising for the algorithm. The simulation which uses the data sourced by National Statistical Office, Bank of Thailand and Ministry of Labour shows good results.

Key words: Markov decision process・Multi-objective Q-learning algorithm・Economic growth・Income equality・Unemployment・Ordinary Least Square

INTRODUCTION

The process leading to the setting the minimum wage has been so far overlooked by economists [1]. Tito Boeri [1] develops a simple model yielding implications as to the relation between the level of the minimum wage and the fixing regime. The model implies that a government legislated minimum wage is lower than a minimum wage set in the context of collective bargaining. The model has a number of predictions as to the relationship between minimum wages. William Brown [2] analyzes the process whereby The Low Pay Commission (LPC) made its decision on the British National Minimum Wage from 1997 to 2007. The key challenges of this analysis were to be independent of government, to have its advice accepted by government and to maintain internal unaminity. His study concludes with the discussion of what the process implies for the concept of "Social Partnership".

Francois Eyraud and Catherine Saget [3] have found that there is strong relation between minimum wage fixing mechanisms and degree of development of collective bargaining. In some countries, bargaining is sufficient structured and institutionalized to play a pivotal role in wage determination, limiting the function of minimum wage fixing to protect the lowest-paid workers. In other countries, the state dominated process of minimum wage setting is only institutional framework available for wage bargaining. They summaries that a minimum wage policy ought to focus on the primary objective of minimum wage, which is to protect the income of the lowest-paid workers and those are least able to formulate their interest in collective bargaining. By assigning the number of roles- combating inflation and unemployment, or even defending market share and attracting foreign direct investment- government may cause the minimum wage to lose its ability to protect the most vulnerable workers. However, Catherine Saget [4] showed developing countries cannot be treated as applying the same minimum wage policy. In particular, it is very different discussing criteria for minimum wage adjustment in these groups of countries where minimum wage serves different purposes than the original one.

Monica D. Castillo [5] describes statistical input required for minimum wage setting, monitor and analysis based on ILO C131 [6]. The ILO C131 is developed by International Labour Organization (ILO) in 1970. This guideline consists of the elements to be taken into consideration in determining the level of minimum wages shall, so far as possible and appropriate in relation to national practice and conditions, appropriate in relation to national practice and conditions, include the needs of workers taking into account the general level of wages in the country (the cost of living, social security benefits and the relative living standards of other social groups

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and their families) and economic factors including the requirements of economic development, levels of productivity and the desirability of attaining and maintaining a high level of employment.

There are several researchers focus on finding the impacts of minimum wage on employment, economic growth and inequality. David Neumark [7] shows conflicting evidence on of income inequality and job loss.

In general, his evidence suggests that it is appropriate to weigh the cost of potential job losses from a higher minimum wage against the benefits of wage increases for other workers. A review of evidence from the new minimum wage research is shown in [8]. The studies that provide convincing evidence of positive employment effects of minimum wages, especially from those studies that focus on the broader groups (rather than a narrow industry) for which the competitive model predicts disemployment effects. The studies that focus on the least-skilled groups provide relatively overwhelming evidence of stronger disemployment effects for these groups. In contrast, the impact of the rising minimum wage from \$4.25 to \$5.05 per hour in New Jersey on April 1992 is evaluated by [9]. They surveyed 410 fast-food restaurants in New Jersey and eastern Pennsylvania before and after the rise. There is no indication that the rise in the minimum wage reduced employment. A theoretical framework which is general enough to allow minimum wages to have the conventional negative impact on employment, but which also allows for the possibility of a neutral or a positive effect is presented [10].

Luciano Fanti and Luca Gori [11] show that the minimum wage can promote economic growth and welfare despite the occurrence of unemployment. A growth-and-welfare-maximizing minimum wage may exist. The economic growth is promoted with an increase in minimum wage and the ratio of public investment to tax revenue [12]. The paper develops a simple two-period overlapping generation model with three economic policies, minimum wage, unemployment benefit and public investment that improves labour productivity. The results from the simple regression of minimum wage on economic growth indicate a positive and statistically significant impact of minimum wage on economic growth both in the long-and short-run in Ghana for period 1984-2013 [13]. Specifically, the results from the other estimations imply minimum wage can only be growth enhancing if it is met by simultaneous increases in investment spending, as well as deliberate and sustained policies aimed at ensuring credit to finance private investment are readily available, easily accessible and affordable. In addition, the ratio of public investment to tax revenue must increase as minimum wage increases since such complementary changes are more likely to lead to economic growth.

Carl Lin and Myeong-Su Yun [14] investigate the contribution of the minimum wage to the well-documented rise in earnings inequality in China over the period from 2004 to 2009 by using city-level minimum wage panel data and a representative Chinese household survey and they find that increasing the minimum wage reduces inequality. David H. Autor, Alan Manning and Christopher [15] find that the minimum wage reduces inequality in the lower tail of the wage distribution, though by substantially less than previous estimates, suggesting that rising lower tail inequality after 1980 primarily reflects underlying wage structure changes rather than an unmasking of latent inequality. Using minimum wage data from Thailand (1985–2010), Attakrit Leckcivilize [16] find that the minimum wage seems to help compress the lower part of wage distribution for employees in large businesses. However, the effect does not extend to small and medium firms in the covered sector. In contrast with its role as a benchmark for wage adjustment in Latin America, the minimum wage in Thailand does not reduce overall wage inequality owing to the high non-compliance rate and weak law enforcement, particularly in the informal sector.

In this paper, the method based A Markov decision process with multi-objective Q-learning for setting minimum wage policy is proposed. This approach is optimized for employment, economic growth and income inequality. The following parts are as follows. In section 2, the selected statistical indicators for employment, economic growth and income inequality are described. The proposed method based on a Markov decision process and multi-objective learning algorithm for multi-objective optimization decision making is shown in section 3. The data and simulation results are shown and discussed in section 4 and section 5 respectively. The conclusion of this research is shown in section 6.

Criteria and Statistical Indicators: Minimum wages are defined as the lowest level of wages that employers are permitted by law to pay to their workers. Minimum wages are always refers to wage rate (per hour, day, month) not total earning or total wage. If they are established adequately high level, minimum wages can help to:

- Increate the earnings of the lowest paid workers
- Reduce the number of "working poor"
- Reduce the gender pay gap
- reduce wage inequality

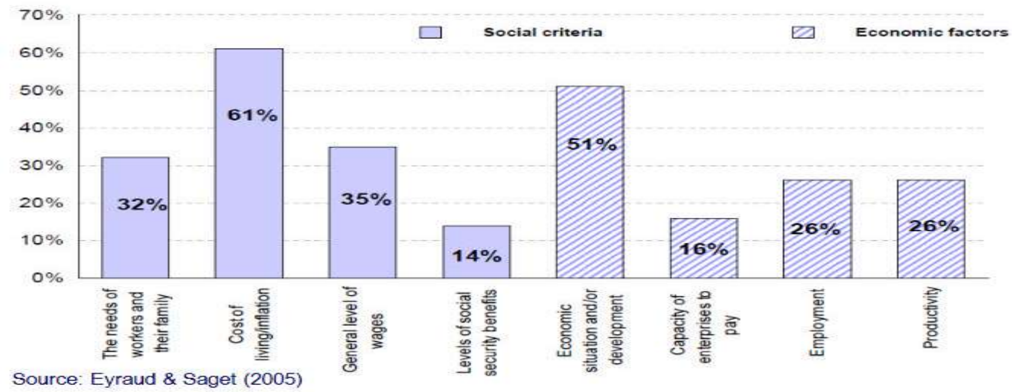

Fig. 1: Criteria used to adjust the minimum wage levels (in %)

Table 1: % of countries that selected the criteria

Criteria for Adjusting Minimum Wage Levels	%
Capacities of employers to pay	26.7
Inflation and/or costing of living	53.3
Economic development	33.3
Level of employment	40
Level of wage and income	40
Needs of workers and their families	46.7
Productivity	26.7
Social security benefits	20

Table 2: Selected statistical indicators for setting minimum wages

Criteria (Objective)	Statistical Indicators
Employment (employment)	Unemployment rate
Economic development (economic growth)	GNP per capita
Cost of living/inflation (economic growth)	Consumer Price Index (CPI)
Needs of worker and their families (income equality)	Average income earnings by household
Level of wage and income (income equality)	GINI coefficient

If they are set too high, the possible adverse effects are:

- Increasing inflation
- Reducing employment
- Reducing economic growth
- Becoming a burden for small and middle enterprises

In 1970, International Labour Organization (ILO) adopted Minimum Wage Fixing Convention No.131 as well as recommendation [6] that both social and economic factors should be taken into account when setting the minimum wage level. Monica D. Castillo [17] suggests that minimum wage setting is needed to clarify on the time units and the components which included excluded. The basic elements of minimum wage policy include:

- Institutional setting: national minimum wage or sectoral minimum wage
- Degree of consultation of the social partners
- Criteria of adjustment: social criteria, economic criteria
- Frequency of adjustment
- Coverage: everybody, sector

The minimum wage legislation provides the criteria, scope of coverage and any particular wage rates for adjusting minimum wage rates regarding:

- Statistical indicators which will be used
- Sources of data
- Lack of data, quality of data issues
- Resources and time frame

Figure 1 shows the criteria described in [6] (both social and economic criteria) used for adjusting the minimum wage level. In Table 1 shows the selected criteria by % of countries [18].

According to the criteria usually used in most of countries as shown in Figure 1 and Table 1, the criteria and statistical indicator which are optimized for employment, economic growth and income equality (GINI coefficient) objectives are selectively considered as input**s** to fix the levels of minimum wage as shown in Table 2.

Makov Decision Process and Multi-objective Q-learning for Minimum Wage Policy: In 1957, Bellman [19] published a book entitled "Dynamic Programming". In the book he presented the theory of a new numerical method for the solution of sequential decision problems. The basic elements of the method are the "Bellman principle of optimality" and functional equations.

In 1960 Howard published a book on "Dynamic Programming and Markov Processes" [20]. As will appear from the title, the idea of the book was to combine the dynamic programming technique with the well established notion of a Markov chain. A natural consequence of the combination was to use the term Markov decision process to describe the notion. Howard also contributed to the solution of infinite stage problems, where the policy iteration method was created as an alternative to the stepwise backward contraction method, which Howard called value iteration. The policy iteration was a result of the application of the Markov chain environment and it was an important contribution to the development of optimization techniques.

A reinforcement learning [21] environment is typically formalized by means of a Markov decision process (MDP). Environment is described by a set of states $S = \{s_1,...,s_N\}$ that is minimum wage rates. A decision-making agent observes the current state of the environment and chooses an action from a given set $A = \{a_1,...,a_N\}$ Nondeterministic effects of actions are described by the set of transition probabilities $T(s'|s,a\}$ which are defined for every pair of states s and s' and for every action a. $P_{3,3,}{}^{a}$ is the probability of reaching state s' from state s after taking an action a. There is a reward function $R(s,a)$ defined on S which specifies an immediate reward of being in a given states, $s \in S$. The goal is to learn a policy π that probabilistically maps states to actions in such as way that expected accumulated future discounted rewards V^{π} is maximized

$$V^{\pi}(s) = E_i\left\{\sum_k^{\infty}\gamma^k r_{t+k+1}\middle| s_t = s\right\} \tag{1}$$

where $\gamma \in [0,1]$ is the discount factor and expectations are taken over stochastic rewards, transitions and action selection with t representing timestamps.

The minimum wage setting problem involves dealing with multiple objectives that are to maximize GDP, income earnings by household and to minimize unemployment, CPI and GINI coefficient. As in many problems there may be multiple (conflicting) objectives, there usually does not exist a single optimal solution. In those cases, it is desirable to obtain a set of trade-off solutions between the objectives. These objectives are considered as rewarded functions in this paper. In order to solve this optimization problem, the multi-objective reinforcement learning (MORL) is adapted.

In multi-objective Markov decision process (MOMDP) [22], a reward vector $\vec{\tau}$ is used where the length of $\vec{\tau}$ denoted as m is the number of reward functions or objectives. For each transition from state-action pair to the next state, a reward function $\vec{R}(s,a) = (R_1(s,a),...,R_m(s,a))$ is given. The values of these functions are estimated by Ordinary Least Squares (OLS) and normalized to [0-1]. In the case of MORL, the state-dependent value function of a state s is vectorial. A solution is a policy ð and is evaluated by its expected return $V^{\pi}(s)$ which is a vector of expected returns for each objective. Thus, the equation (2) is

$$V^{\pi}(s) = E_i\left\{\sum_k^{\infty}\gamma^k R_1\middle| s_t = s\right\},...E_i\left\{\sum_k^{\infty}\gamma^k R_m\middle| s_t = s\right\} \tag{2}$$

Recently, a general framework for scalarized single-policy MORL algorithms is proposed [23]. In the framework, scalar $\ddot{Q}$-values are extended to $\ddot{Q}$-vectors that store a $\ddot{Q}$-value for each objective

$$\hat{Q}(s,s) = (\hat{Q}_1(s,a),...,\hat{Q}_m(s,a)) \tag{3}$$

The scalarized multi-objective Q-learning algorithm is presented in the following Algorithm. At line 1, the $\ddot{Q}$-values for each triplet of states, actions and objectives are initialized. The agent starts each episode in state s (line 3) and chooses an action based on the multi-objective action selection strategy at line 5 that is ε-greedy. With ε-greedy, the agent selects at each time step a random action with a fixed probability, $0 \le \varepsilon \le 1$, instead of selecting greedily one of the learned optimal actions with respect to the Q-function:

$$\pi(s) = \begin{cases} ramdan\ action\ from\ A(s)\ if\ \ \varphi < \varepsilon \\ \text{argmax}_{a \in A(g)} Q(s,a) \qquad otherwise \end{cases} \tag{4}$$

where 0 = φ = 1 is a uniform random number drawn at each time step. Upon taking action a, the environment transitions the agent into the new state s' and provides the vector of sampled rewards r. As the Q-table has been extended to incorporate a separate value for each objective, these values are updated for each objective individually and the single-objective Q-learning update rule is extended for a multi-objective environment at line 9. More precisely, the $\ddot{Q}$-values for each triplet of state s, action a and objective o are updated using the corresponding reward for each objective, r, into the direction of the best scalarized action of the next state *s*'. It is important to note that this framework only adds a scalarization layer on top of the action selection mechanisms of standard reinforcement learning algorithms.

Scalarized Multi-objective Q-learning Algorithm:

1: Initialize $\ddot{Q}_o(s,a)$ *arbitrarily*
2: for each episode t do
3: Initialize state s
4: repeat
5: Choose action a from s using the policy derived from $\overline{SQ}$ *-values*
6: Take action a and observe state s ← *S and reward vector r* ← R_m
7: à ← greedy(s')
8: for each objective o do
9: $\ddot{Q}_o(s,a) \leftarrow \ddot{Q}_o(s,a) + a_t(r_o + \gamma\ \ddot{Q}_o(s,a) - \ddot{Q}_o(s,a))$
10: end for
11: s ←s Proceed to next state
12: until s is terminal
13: end for

A scalarization function can come in many forms and favors, but the most common function is the linear scalarization function. As depicted in Eq. 5, the linear scalarization function calculates a weighted-sum of the $\ddot{Q}$-vector and a non-negative weight vector.

$$\overline{SQ}_{linear}(s,a) = \sum\nolimits_{0=1}^{m} w_o \ddot{Q}_o(s,a) \quad (5)$$

The weight vector itself should satisfy the equation.

$$\sum_{o=1}^{m} w_o = 1 \quad (6)$$

Given these $\overline{SQ}$ -values, the standard action selection strategies can decide on the appropriate action to select. For example, in the greedy case in Eq. 7, the action with the largest $\overline{SQ}$ -values is selected.

$$greed_{ylinear}(s) = \arg_a,\max \overline{SQ}_{linear}(s,a') \quad (7)$$

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Total	1.4	1.4	1.5	1.0	0.7	0.7	0.7	0.8	0.9	1.0
Male	1.5	1.5	1.5	1.1	0.7	0.7	0.8	0.9	0.9	1.0
Female	1.2	1.3	1.4	1.0	0.6	0.6	0.7	0.8	0.9	1.0

Fig. 2: Unemployment rates of Thailand

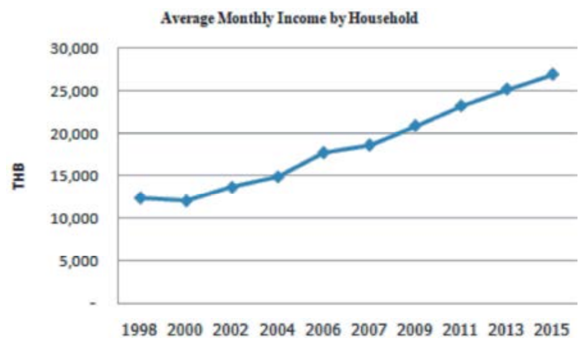

Fig. 3: Average monthly income by household

Table 3: Data and Data Sources

Statistical Indicators	Sources
Unemployment rate	National Statistical Office [24]
GNP per capita	Bank of Thailand [25]
Consumer Price Index (CPI)	Bank of Thailand [25]
Average income earnings by household	National Statistical Office [24]
GINI coefficient	National Statistical Office [24]
Minimum wage rate	Ministry of Labour [26]

Data Explanation: The data for this paper consists of three main data sources: Bank of Thailand, Ministry of Labour and National Statistical Office, Ministry of Information and Communication of Thailand. Table 3 shows data and data sources used in this paper. In Figure 2, the data of unemployment rate (2007-2016) in Thailand is shown and classified by male, female and total.

In Figure 3, the average monthly income by household (1998-2015) in Thai Baht (THB) currency is shown. The GINI coefficient (1998-2015) is shown in Figure 4. The data (1989-2017) of Consumer Price Index (CPI) are shown in Figure 5 and Figure 6. In Figure 7, the GNP per capita (1990-2015) sourced by the Bank of Thailand is shown as GNP in Thai Baht (THB) currency per person.

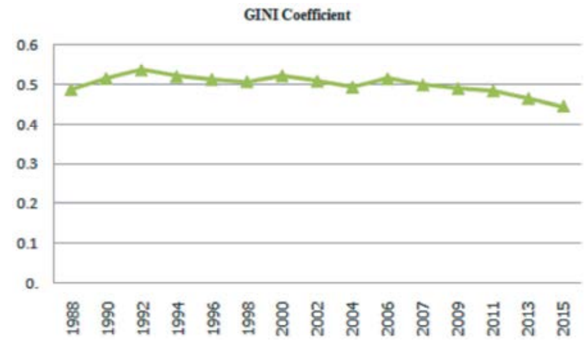

Fig. 4: GINI coefficient

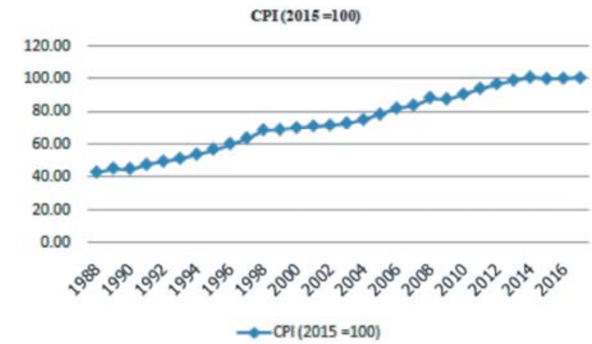

Fig. 6: CPI

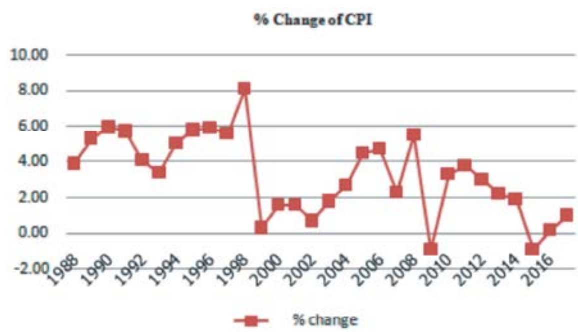

Fig. 5: % Change of CPI

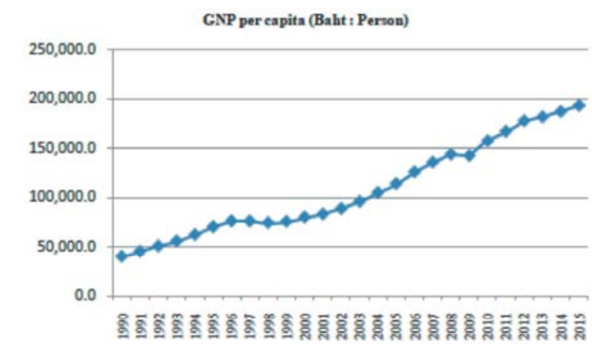

Fig. 7: GNP per capita (THB : person)

Table 4: Minimum wage rate (per day) of Thailand from 2001-2016 in Thai Baht (THB)

Provinces		‘01	‘02	‘03	‘04	‘05	‘06	‘07	‘08	‘09	‘10	‘11	‘12	‘13	‘14	‘15	‘16
Bangkok	Bangkok	165	165	169	169	170	175	181	184	191	194	203	203	206	215	300	300
Central Region	Nakon Pathom	165	165	169	169	170	175	181	184	191	194	203	203	205	215	300	300
	Nonthaburi	165	165	167	167	170	175	181	184	191	194	203	203	205	215	300	300
	Pathum Thani	165	165	169	169	170	175	181	184	191	194	203	203	205	215	300	300
	Samut Prakan	165	165	169	169	170	175	181	184	191	194	203	203	206	215	300	300
	Samut Sakhon	165	165	165	169	170	175	181	184	191	194	203	203	205	215	300	300
	Chai Nat	133	133	135	135	135	139	142	142	146	149	154	154	158	167	233	300
	Ayudhaya	133	133	139	139	142	146	152	155	160	165	173	173	181	190	265	300
	Lop Buri	133	133	133	133	136	140	146	151	155	158	163	163	170	182	254	300
	Saraburi	143	143	148	148	151	155	161	163	168	170	179	179	184	193	269	300
	Sing Buri	133	135	135	135	136	140	145	147	152	156	161	161	165	176	246	300
	Ang Thong	133	138	138	138	138	142	146	148	152	154	161	161	165	174	243	300
	Chantaburi	133	133	135	135	138	142	146	150	155	158	163	163	167	179	250	300
	Chachoengsao	133	137	137	137	140	144	150	153	160	165	173	173	180	193	269	300
	Chonburi	143	146	150	150	153	157	163	166	172	175	180	180	184	196	273	300
	Trat	133	133	135	135	135	139	145	145	149	150	156	156	160	169	236	300
	Nakornnayok	133	133	134	134	134	138	141	143	147	150	156	156	160	170	237	300
	Prajinburi	133	133	135	135	136	140	145	147	152	155	163	163	170	183	255	300
	Rayong	133	133	141	141	143	147	153	155	161	165	173	173	178	189	264	300
	Sa Kaeo	133	133	133	133	137	141	145	147	154	155	160	160	163	173	241	300
	Ratchaburi	133	133	135	135	138	142	147	147	154	156	164	164	167	180	251	300
	Kanchanaburi	133	133	135	135	138	142	148	151	155	157	165	165	169	181	252	300
	Suphan Buri	133	133	133	133	136	140	143	145	149	149	154	154	158	167	233	300
	Samut Songkhram	133	133	133	133	138	142	147	150	154	155	160	160	163	172	240	300
	Petchaburi	133	133	136	136	138	142	147	150	156	160	164	164	168	179	250	300
	Prachuap Khiri Khan	133	133	133	133	135	139	147	147	152	152	160	160	164	172	240	300
Nothern Region	Chiang Mai	143	143	143	143	145	149	153	155	159	159	168	168	171	180	251	300
	Lamphun	133	133	137	137	137	141	145	145	149	152	156	156	160	169	236	300
	Lampang	133	133	133	133	135	139	143	145	149	149	154	154	156	165	230	300
	Uttaradit	133	133	133	133	135	139	143	143	147	147	149	152	153	163	227	300
	Phrae	133	133	133	133	133	137	140	140	144	146	150	150	151	163	227	300
	Nan	133	133	133	133	133	137	140	140	143	144	151	151	152	161	225	300

Table 4: Continued

Provinces		'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16
	Phayao	133	133	133	133	133	137	140	140	144	144	150	150	151	159	222	300
	Chiang Rai	133	133	133	133	133	137	142	142	146	146	157	157	157	166	232	300
	Mea Hong Son	133	133	133	133	133	137	141	141	145	147	151	151	151	163	227	300
	Nakon Sawan	133	133	133	133	135	139	143	143	147	150	155	155	158	166	232	300
	Uthaithani	133	133	135	135	135	139	142	142	146	150	158	158	158	168	234	300
	Khampaeng Phet	133	133	135	135	136	140	143	143	147	149	156	156	158	168	234	300
	Tak	133	133	133	133	135	139	143	143	147	147	151	151	153	162	226	300
	Sukhothai	133	133	137	137	137	141	145	145	149	149	151	153	153	165	230	300
	Phitsanulok	133	133	133	133	135	139	143	143	147	148	152	152	153	163	227	300
	Phichit	133	133	133	133	134	138	141	141	145	146	150	150	151	163	227	300
	Phetchabun	133	133	135	135	135	139	143	143	147	150	155	155	155	166	232	300
Noth Eastern Region	Nakon Ratchasima	143	143	145	145	145	150	156	158	162	165	170	170	173	183	255	300
	Buri Ram	133	133	136	136	136	140	144	144	148	150	155	155	157	166	232	300
	Surin	133	133	133	133	133	137	141	141	145	147	151	151	153	162	226	300
	Srisaket	133	133	133	133	135	139	142	142	146	146	150	150	152	160	223	300
	Ubol Ratchathani	133	133	133	133	133	137	141	141	145	145	154	154	160	171	239	300
	Yasothon	133	133	133	133	133	137	142	142	146	147	155	155	157	166	232	300
	Chaiyaphum	133	133	133	133	135	139	142	142	146	146	148	152	156	165	230	300
	Amnat Charoen	133	133	133	133	135	139	141	141	145	145	153	153	155	163	227	300
	Nong Bua Lam Phu	133	133	135	135	135	139	142	142	146	148	154	154	156	165	230	300
	Khon Kaen	133	133	136	136	136	140	144	144	148	150	154	154	157	167	233	300
	Udonthani	133	133	133	133	135	139	144	145	150	150	157	157	159	171	239	300
	Loei	133	133	133	133	135	139	144	144	150	154	162	162	163	173	241	300
	Nong Khai	133	133	133	133	135	139	142	144	148	150	157	157	159	169	236	300
	Bueng Kan															236	300
	Maha Sarakham	133	133	133	133	133	137	140	142	146	147	151	151	154	163	227	300
	Roi Et	133	133	133	133	135	139	142	142	146	147	154	154	157	166	232	300
	Kalasin	133	133	135	135	135	139	144	144	148	148	155	155	157	167	233	300
	Sakol Nakon	133	133	133	133	135	139	142	142	146	148	155	155	157	166	232	300
	Nakon Phanom	133	133	135	135	135	139	142	144	148	148	153	153	155	164	229	300
	Mukdahan	133	133	133	133	135	139	142	142	146	148	153	153	155	165	230	300
Sothern Region	Nakon Sri Thammarat	133	133	133	133	135	139	142	144	148	150	155	155	159	174	243	300
	Krabi	133	133	138	138	140	144	148	151	156	160	165	165	170	184	257	300
	Phangnga	143	143	143	143	145	149	153	155	159	162	168	168	173	186	259	300
	Phuket	165	168	168	168	168	173	178	181	186	193	197	197	204	214	300	300
	Surat Thani	133	133	135	135	135	139	143	143	147	150	155	155	159	172	240	300
	Ranong	143	143	143	143	143	147	153	155	160	163	169	169	173	185	258	300
	Chumphon	133	133	135	135	137	141	145	145	149	150	158	158	160	173	241	300
	Song Khla	133	133	135	135	135	139	144	144	152	152	157	157	161	176	246	300
	Satun	133	133	133	133	135	139	144	144	148	150	155	155	159	173	241	300
	Trang	133	133	133	133	136	140	145	148	152	154	157	157	162	175	244	300
	Phatthalung	133	133	133	133	135	139	143	143	147	150	155	155	159	173	241	300
	Pattani	133	133	133	133	135	139	144	144	148	148	155	155	159	170	237	300
	Yala	133	133	133	133	135	139	144	144	148	148	155	155	160	172	240	300
	Narathiwat	133	135	135	135	135	139	139	144	148	148	153	153	160	171	239	300

In Table 4, the minimum wage rates (per day) of Thailand's provinces are shown in Thai Baht (THB).

RESULS

In this experiment, the data of Bangkok's minimum wage rates are used as a set of states, $s \in S$ and the % of rising are used as a set of actions, $a \in A$. The value of discount factor that is Gamma, γ, is set to 0.7 and the number of objectives are three (minimizing unemployment, maximizing economic growth and maximizing income equality). The weights, W_o, of these objectives are set equally to {0.333, 0.333, 0.333} for Eq. (5). These weight factors can be changed based on policy decision makers to emphasize their minimum wage policy. The probabilities $P_{3,3}{}^{a}$ are set equally for all reaching state s' from state s after taking an action a. The matrix of $Q(s,a)$ values are initialized to zero as shown in Figure 8 at stating point. The states in rows no. 1-16 are the minimum wage rates of Bangkok from year 2001 to 2016. The "new" state in state no. 17 is the goal state or required result of the year 2017 which is needed to estimate the total rewards and then decide the new minimum wage rate. The actions in columns no. 1-16 are the rising in percent of minimum wage rates from year 2001 to 2016. The actions no. 17-20 (10%, 15%, 20%, 25%) are rising rates newly defined for action simulation by the Markov decision process with multi-objective Q-learning algorithm. The proposed method calculates total reward of each action and each year. The results of five reward functions that OLS is used

		Action																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
		0.0%	0.0%	2.4%	0.0%	0.6%	2.9%	3.4%	1.7%	3.8%	1.6%	4.6%	0.0%	1.5%	4.4%	39.5%	0.0%	10.0%	15.0%	20.0%	25.0%
	1 165	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2 165	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3 169	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4 169	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5 170	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6 175	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7 181	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	8 184	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
State	9 191	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	10 194	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	11 203	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12 203	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	13 206	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	14 215	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15 300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	16 300	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	17 new	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Fig. 8: Initialized zero matrix Q

		Action																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
		0.0%	0.0%	2.4%	0.0%	0.6%	2.9%	3.4%	1.7%	3.8%	1.6%	4.6%	0.0%	1.5%	4.4%	39.5%	0.0%	10.0%	15.0%	20.0%	25.0%
	1 165	-2.84	-2.84	-2.84	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.84	-2.83	-2.84	-2.82	-2.83	-2.84	-2.84	-2.83	-2.84	-2.84
	2 165	-2.84	-2.83	-2.83	-2.83	-2.83	-2.83	-2.84	-2.84	-2.82	-2.83	-2.83	-2.84	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.84
	3 169	-2.83	-2.84	-2.84	-2.83	-2.83	-2.83	-2.84	-2.83	-2.83	-2.83	-2.83	-2.84	-2.84	-2.83	-2.84	-2.83	-2.83	-2.83	-2.83	-2.83
	4 169	-2.84	-2.83	-2.83	-2.83	-2.83	-2.84	-2.84	-2.83	-2.83	-2.84	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.84	-2.83
	5 170	-2.83	-2.83	-2.83	-2.83	-2.77	-2.84	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.84	-2.83	-2.83	-2.77	-2.83
	6 175	-2.84	-2.84	-2.83	-2.70	-2.84	-2.83	-2.84	-2.84	-2.83	-2.83	-2.83	-2.83	-2.84	-2.83	-2.84	-2.84	-2.84	-2.84	-2.83	-2.84
	7 181	-2.84	-2.84	-2.83	-2.84	-2.84	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.84	-2.84	-2.84	-2.80	-2.83	-2.84	-2.84	-2.80
	8 184	-2.84	-2.83	-2.84	-2.84	-2.83	-2.84	-2.83	-2.84	-2.83	-2.83	-2.83	-2.83	-2.84	-2.83	-2.84	-2.84	-2.84	-2.84	-2.83	-2.83
State	9 191	-2.83	-2.84	-2.84	-2.83	-2.83	-2.84	-2.83	-2.84	-2.84	-2.84	-2.84	-2.84	-2.84	-2.84	-2.83	-2.84	-2.83	-2.84	-2.83	-2.84
	10 194	-2.84	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.84	-2.83	-2.83	-2.83	-2.82	-2.84	-2.84	-2.83	-2.83	-2.83	-2.83	-2.83
	11 203	-2.83	-2.83	-2.83	-2.83	-2.84	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.80	-2.83	-2.83	-2.83	-2.83	-2.83
	12 203	-2.83	-2.79	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83
	13 206	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.84	-2.77	-2.83	-2.83	-2.83	-2.83	-2.84	-2.83	-2.84	-2.83	-2.83	-2.83	-2.83
	14 215	-2.83	-2.83	-2.83	-2.83	-2.83	-2.84	-2.83	-2.83	-2.83	-2.83	-2.84	-2.83	-2.83	-2.83	-2.84	-2.83	-2.83	-2.83	-2.83	-2.83
	15 300	-2.83	-2.83	-2.83	-2.83	-2.83	-2.80	-2.83	-2.83	-2.83	-2.83	-2.84	-2.83	-2.83	-2.84	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83
	16 300	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.84	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.84	-2.83
	17 new	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.83	-2.84	-2.83	-2.84	-2.80	-2.84	-2.70	-2.84	-2.84	-2.84	-2.84	-2.84	-2.84	-2.84

Fig. 9: The value of $\overline{\overline{SQ}}_{linear}(s,a)$ at 1000 iterations

Table 5: OLS based reward functions

Indicator	Weight	Reward Function
Unemployment	1.0	$Y = 1.023 - 0.2907\ X$
GNP per capita	0.5	$Y = 0.0652 - 0.0939\ X$
CPI	0.5	$Y = 3.6768 + 7.0461\ X$
Average Income by household	0.5	$Y = 0.0574 + 0.0392\ X$
GINI coefficient	0.5	$Y = 0.4949 - 0.1315\ X$

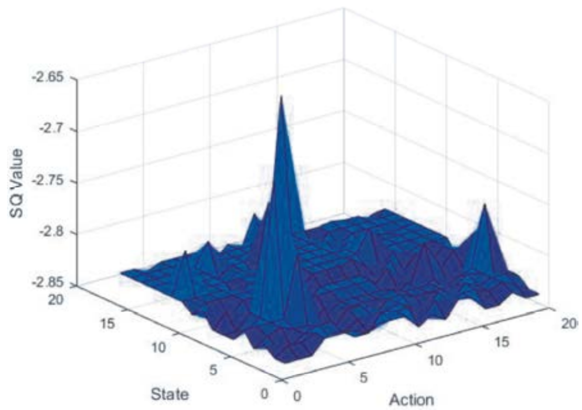

Fig. 10: The results of $\hat{S}\hat{Q}_{linear}(s,a$ in 3D

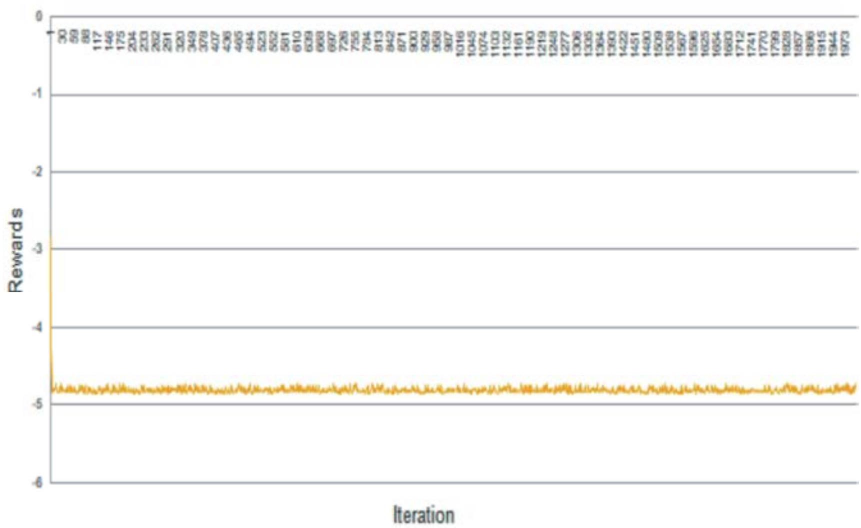

Fig. 11: The average reward values over 2000 iterations

for estimating the reward values are shown Table 5 and reward values are normalized to [0-1]. The OLS estimations for reward functions show positive impacts to CPI and average income by household and negative impacts to unemployment, GNP per capita and GINI coefficient depending on percentage of rising minimum wage, *X*. The reward functions for GNP per capita supporting to economic growth objective and average income by household supporting to income equality objective are maximized and set to positive values. In contrast, the reward functions for unemployment supporting to employment objective, % of CPI changes supporting to economic growth and GINI coefficient supporting to income equality are minimized and set to negative values. The weight factors are defined based on objectives and reward functions, 1.0 for unemployment reward function (employment objective), 0.5 for GNP per capita and CPI reward functions (economic growth objective) and 0.5 for average income by household and GINI coefficient reward functions (income equality objective).

In Figure 9, the final values of $\overline{S}\overline{Q}_{linear}(s,a)$ at 2000 iterations are shown. The values are negative due to three minimized reward functions and two maximized reward functions. According to $\overline{S}\overline{Q}_{linear}(s,a)$ values calculated by Eq. (5), the policy makers can select the rising rate in percent that is the maximum the reward value defined by Eq. (7). In this case, the action no. 13 is suggested. In figure 10, the simulation results of $\overline{S}\overline{Q}_{linear}(s,a)$ of 2000 iterations are shown in 3D perspective which shows obviously optimized value. The average reward values based on the five reward functions over 2000 iterations are shown in Figure 11.

CONCLUSION

In this paper, the Markov decision process with multi-objective Q-learning is proposed for setting minimum wage rate by estimating total reward values of five reward functions supporting to three objective that are employment, economic growth and income equality. The data from the Bank of Thailand, the National statistical Office and the Ministry of Labour of Thailand are used for this simulation. The minimum wage rate of Bangkok is used for states and actions of this experiment. The weight of each objective and rising rates in percent can be determined before running the algorithm. The experimental results shows total reward values of each action then the maximum value is selected for new rising rate and then new minimum wage rate can be defined.

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