行政院國家科學委員會專題研究計畫 成果報告

從代理人工程到市場設計:建構以代理人基建模為基礎之整合平台(第 3 年)
研究成果報告(完整版)

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報 告 附 件 : 出席國際會議研究心得報告及發表論文

處 理 方 式 : 本計畫可公開查詢

中 華 民 國 98 年 11 月 06 日

行政院國家科學委員會補助專題研究計畫　成果報告

從代理人工程到市場設計：

建構以代理人基建模為基礎之整合平台

計畫類別：■ 個別型計畫
計畫編號：NSC 95－2415－H－004－002－MY3
執行期間：　　95 年　8 月　1 日至　98 年　7 月　31 日

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成果報告類型(依經費核定清單規定繳交)：□精簡報告　■完整報告

本成果報告包括以下應繳交之附件：
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□國際合作研究計畫國外研究報告書一份

處理方式：可公開查詢

執行單位：國立政治大學經濟學系

中　華　民　國　　　98 年　　　10 月　　　31 日

從代理人工程到市場設計：
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摘要

　　本計畫之研究宗旨在於探究經濟決策者之計算力（computational capacity）與其行為與結果的影響。計算能力在決策者身上所造成的影響，可能會在決策者所採用的策略，以及其決策的結果上顯示出效果。經濟決策個體在計算力上之差異，在過去的研究中鮮少在市場環境中對這個重要的因子進行觀察與分析。本研究提出一個可以進行電腦模擬與真人實驗的平台，透過電腦模擬與真人實驗的方式同時針對計算力的影響進行觀察。

　　本計畫首先透過一個線上期貨市場來進行實驗，在此市場中允許真人與軟體輔助工具並存，來探究真人的決策選擇行為。其次，我們透過代理人基模型來分析計算力在具有學習能力的軟體代理人身上所造成的影響。最後，我們透過真人實驗，並且搜集分析真人受試者的工作記憶容量（working memory capacity）來進行相同的實驗比對。

　　我們的實驗結果發現，計算能力在具有學習能力的軟體代理人身上可以看到明確顯著的影響。而在真人身上，在以雙方喊價市場為主的環境中，在多數市場中效果不顯著，但在某些特定市場裡有顯著效果。

關鍵字：計算力、工作記憶、期貨市場、雙方喊價市場、實驗經濟學、代理人基模擬經濟　　　　學

From Agent Engineering to Market Design:
An Integrated Platform Based on an Agent-Based Simulation Framework

Abstract

Computational capacity is one the sources of bounded rationality of human decision makers, and therefore should be an important factor to consider in models with heterogeneous agents. However, it is not well investigated in economic literature, except some studies of games.

In this project, we proposed two methods to study the influences of computational capacity on decision makers: human experiments and agent-based computational models. There are three ways to manipulate or to access the computational capacity on these markets, they are: decision-support systems, populations sizes as the proxy variable, and a direct measure of working memory. Our results shows that computational capacity plays an important role for software agents with learning ability, while its influences on human decision-makers may depend on the markets where traders are participating.

目錄

一、前言

在經濟學的研究議題中，個體能力差異所造成的分配問題，往往涉及道德與價值的判斷而顯得棘手而難以辨明。十九世紀著名的經濟學家柏瑞圖（Vilfredo Pareto），是早期在這方面最著名的研究者。柏瑞圖研究了歐美諸多國家的財富分配，得到了一個跨越族裔、文化、時間、開發程度等因素的共通現象—一個社會中的財富分配，並非呈現對稱的鐘形分配，而是極小部分的人掌握了絕大多數的財富。這個迴異於常態的分配，便因此被稱作 Pareto 分佈（Pareto distribution, 即 power-law distribution），而這個現象也被稱作 Pareto Principle（亦稱作 80-20 法則）。

發現了財富分佈極度不均的現象之後，該如何解釋這樣的現象呢？柏瑞圖的見解是：社會的菁英階層（Elite）囊括了絕大多數的資源，不論歷史和制度如何更替，即使在民主制度下，這樣的菁英階層（或曰上層階級，the aristocracies）也許組成分子有別，但仍一直存在不滅。結果是愈聰明和愈有能力的人，所得到的資源也會愈來愈多。

當現代經濟學家重新看待個體心智能力差異問題時，雖然儘量嘗試由客觀的統計數字所提供的資訊來尋找可能的原因，但仍難免因為道德問題而使得此議題的重要性遭到糊模。Herrnstein and Murray (1994) 的《鐘形曲線：美國社會中的智力與階層結構》（The Bell Curve: Intelligence and class structure in American life）一書，利用智商作為衡量人類智能的依據，進而探討人類智慧和社會結構之關係。由各項的數據揭露出智商對於人們社會成就、工作表現、薪資等等面向的重大影響。

在後續的相關研究中，Murray (1998) 及 Murray (2002) 利用生長條件相同但智商不同的手足資料，在智商差異對所得、學習成就、職業等結果的影響上，得到了明確而且統計上顯著的結果。很明顯地，若要探究個體能力差異所造成的所得不均現象，智商可作為相當重要的代表因素。

那麼，計算能力和智商之間的關係是什麼？智商衡量的又是什麼呢？智商是心理測驗學（Psychometrics）中用以衡量智能（intelligence）的一套方法。而智能在心理學中的定義，是指一種用以**推理、計畫、解決問題、抽象思考、理解複雜概念、及學習**（learn quickly and learn from experiences）的綜合能力。而計算能力則也是一個抽象的概念，它泛指人類在解決問題時所能用到的計算能量。因此，兩者可視為是同樣指稱人類認知能力的概念。

倘若個體計算能力代表個體思考問題、解決問題、與學習的能力，對人們的經濟行為有著決定性的影響，那麼我們在建構一個可以描述個體行為差異的模型時，便應該將其納入描述個體的行為或特性中，但問題是：個體計算能力（心智能力）的差異到底為以什麼樣的形式展現出來？我們在建立模型時，又該如何將計算能力這個變數納入模型之中呢？

二、研究目的

本研究計畫的目的有兩個：一個是進行真人實驗，來探討個體計算能力對其在市場中行為的影響；二是找出一個建模由具備不同計算能力的決策個體所組成的異質代理人模型（heterogeneous-agent model）。

為了探討個體計算能力差異所造成的影響，我們必須進行真人實驗，並直觀察計算能力差異的效果。而針對決策者的計算能力這個變數，我們可以採取兩種可能的作法：一是直接給予操弄，二則是加以測量。

而在建模方面，一個由異質化經濟個體所組成的市場將難以利用數學方式描述，故唯一可行的方法便是建立計算模型。因此，本研究的另一目的，便是尋找一個能夠在代理人基計算模型（agent-based computational models）中納入個體心智能力這個變數，提出一個可操作的方法並且進行實際模擬。

本研究因此搭配電腦模擬與真人實驗，嘗試針對以上所述的問題提出回答。本報告接下來將在第四節文獻探討部分介紹經濟學界目前在這些議題上的進展；第五節研究方法將簡介本計畫所使用的各種實驗方法、工具、以及實驗設計；第六節結果與討論將簡述本計畫所得到的各項實驗成果與結論。本計畫的詳細實驗設計細節與成果圖表，則是在已發表的各項論文中逐一列舉。

三、文獻探討

在經濟學文獻中，直接探討個體心智能力對決策影響的文獻相當有限，在此可分為實驗經濟學、真人與軟體互動實驗、數理模型、以及代理人基建模四大部分。

統計模型

在現今的經濟學理論或計量文獻中，探討心智能力對人類社會乃至於國家之間所得不均的研究也是相當稀少。Lynn and Vanhanen（2002, 2006）的研究認為國家平均智商可以解釋國家財富與經濟成長率的差異；Jones and Schneider（2006）發現智商可作為人力資源的有效衡量方法，並且在統計上成功地利用國家平均智商來解釋 GDP 成長的差異；Ram（2007）則正式將智商納入 Mankiw-Romer-Weil 成長模型中，並利用國家平均智商與 GDP 資料，發現 IQ 比教育及健康兩項要素更能代表人力資源的品質，而且甚至比制度品質（institutional quality）還重要。

這部分的研究雖然將心智能力的影響正式納入經濟學的模型之中，透過事後的統計分析來解釋國與國之間財富與人力資源的差異，卻無法幫助我們進一步理解心智能力何以會對經濟選擇的結果造成影響。也就是說，我們仍需要一個由個體層級的角度，來描述及理解心智能力效果的模型。在目前經濟文獻中，則是由實驗經濟學及代理人基計算模擬在這一塊開始提出了一些具體的實驗結果，其發現將分述於下。

實驗經濟學

在實驗經濟學領域中，一直到近幾年才開始有研究者以真人實驗來探討心智能力在決策行為上的影響。心智能力（cognitive capacity）並不是一個精確的名詞，它泛指個體在解決問題、學習、推理的過程中所可以運用的心智資源多寡。因此在實驗經濟學中，研究者會透過不同的方式來加以衡量或操弄。若要進一步探究心智能力多寡在決策上所造成的影響，則可以採兩種方式：加以操弄或以測驗的方式來測量。

Devetag and Warglien（2003）是率先打開這方面研究的鋒之一。他們的實驗顯示在賽局實驗中，決策者的推理層級（depth of reasoning）會受到自身短期記憶（short-term memory, STM）容量的影響。Nagel（1999）以及 Ohtsubo and Rapoport（2006）要求受試者執行一系列衡量心智能力的問題（imposing memory task, IMT）來間接觀測受試者在思考判斷時可用的心智資源多寡。他們的研究發現受試者的 IMT 與他們在選美預測賽局（beauty contest game）上所展現出來的推理層級有正向的關係。Devetag and Warglien

（2008）的實驗則則進一步顯示出，受試者的短期記憶能力與他們在賽局中的表現僅有在中等難度的賽局中呈正相關，在較難和較簡單的賽局中則無顯著關係。Segal and Hershberger（1999）採取另一種衡量心智能力的方法，他們用智商（IQ）作為心智能力的代表，他們的實驗顯示出受試者的智商和他們在重覆的囚犯賽局中合作的程度呈正相關。

另一方面，也有學者透過要求受試者執行一系列會佔用他們心智能力的工作來影響他們在正式項目上可使用的心智資源多寡，來探討心智能力對決策結果的影響。在 Cornelissen, Dewitte, and Warlop（2007）的實驗中，若受試者的心智資源遭佔用得較嚴重（換言之可使用的心智資源便較少）時，受試者在獨裁賽局（dictator game）中會表現得較大方。然而，利用類似的方法，Cappeletti, Guth, Ploner（2008）的實驗則顯示出短期記憶和受試者在最後通牒賽局（ultimatum game）的行為無顯著關係。

然而，過去經濟學的文獻所探討的主題，多半是在賽局的環境裡進行的。經濟個體在市場的行為是否會受其心智能力的影響，仍尚未見得相關的文獻出現。因此本研究便在市場的環境中進行真人實驗，以瞭解人類的交易決策行為與其心智能力的關係。

代理人基建模

在代理人基建模中，Casari（2004）是唯一將個體的心智能力明確納入學習性決策者經濟選擇行為中的模型。Casari（2004）利用遺傳演算法（genetic algorithm, GA）作為軟體決策者學習的演算法，用來解釋實驗室中人類決策者在共享資源問題（common pool resources, CPRs）實驗中的有限理性行為，以及個體之間的差異。Casari（2004）利用 GA 決策者的策略染色體數目（population size）作為其工作記憶的代表變數，並成功複製了真人受試者在 CPR 實驗所展現出來的大部分模式。

Casari（2004）的模型可說是將心智能力納入代理人基經濟建模的第一步，但其模型有兩項明顯的限制：（1）使用 GA 來描述決策者的學習過程有其局限性，因為 GA 決策者的策略中所包括的元素均由研究者所指定，因此 GA 決策者會採用何種類型的策略其實會受到研究者指派變數時的限制。（2）CPR 實驗是一個賽局實驗，而對於一般的經濟市場而言，心智能力對人們決策的影響到底何？則仍有待進一步的研究。

因此，本研究乃鎖定期貨市場及雙方喊價市場作為實驗環境，並且在代理人基建模上採用遺傳程式設計（genetic programming, GP）作為決策者學習的演算法，以賦予軟體決策者更全面的學習能力。

四、研究方法

承前所述，本研究計畫在當前文獻中將佔有以下幾個重要的位置：

1. 以真人受試者進行市場實驗，以取得更為直接的個體決策資料，來探討認知能力對個體經濟決策的影響。

2. 以市場作為實驗的主要環境，較能直接引導出人類決策者在一般經濟行為中受計算能力影響的層面。

3. 藉由代理人基模型，找出更佳的方法來描述個體的計算能力上的差異性，為將來的異質性經濟模型中提出解決方案。

是故在研究方法上，我們必須採取不同的組合進行實驗，並且加以比較，才能獲取理想的資料進行分析研究。因此我們將針對市場、計算能力之衡量、以及模擬與實驗之配合作出選擇。表一是本計畫中所使用的研究方法表。

表一　實驗類型與研究方法表

實驗類別	實驗方式	實驗環境	實驗平台	計算能力處理方式
A	真人實驗	期貨市場	線上期貨市場 AI-EON FX	提供決策支援工具，以提升受試者的計算能力（減輕其計算負擔）。
B	代理人基模擬（軟體代理人）	雙方喊價市場	代理人基單機模擬程式 AIE-DA	利用策略數目作為軟體決策者認知能力之描述變數。
C	真人＋軟體代理人混合實驗	雙方喊價市場	網路版 AIE-DA	利用工作記憶容量測驗（working memory capacity tests）來衡量真人受試者的工作記憶大小。

對於本研究計畫所使用到的實驗平台及實驗設計，茲分述如下：

線上期貨市場

於此研究中，我們首先建立以網際網路作為架構的線上實驗市場平台—政大"事件期貨"交易市場（AI-ECON Futures Exchange, AI-ECON FX）。AI-ECON FX 是一個 24 小時開放的線上期貨市場，招募來的受試者在註冊填寫基本資料之後，便可參與市場的交易活動。在註冊完畢後，受試者帳戶中會有 30,000 虛擬貨幣供其交易。整個市場交易活動的目的是對某一真實事件進行預測。在本計畫中，我們針對 2006 年的北高市長選舉進行預測。期貨的契約價格便代表對各候選人最後的實際得票率之預測。整個實驗共進行了 30 天，在選舉前一天結束。開票後，受試者帳戶中的期貨契約依照實際得票率來換算結清價值。而所有的受試者將依表現排名領取事先公佈的定額獎金。

受試者的表現將依其預測準備性以及其交易策略而決定。原則上所有的候選人得票率總和會是 100%，所以在市場上所以契約的價格總和理論上最高會是 100。然而由於各受試者的預測不同，因此市場上契約價格總和時常會偏離 100 的水準。而一旦價格總和偏離 100，就意味著有套利（arbitrage）的空間——交易者可以不同的策略間下單分別進行買賣，直到契約價格總和回到 100 的合理狀況為止。因此，由於有多組契約，除了要考量契約價格總和外，還要對每組契約的價格是否過高或過低進行判斷，同時還要儘快在市場上遞單（因為同價格的訂單成交的順序以其遞送到市場上的先後為根據），是一個非常耗費計算量的工作。

因此在實驗中，我們除了讓受試者自行交易外，也提供了一個決策支援工具讓其選擇。這個工具可以幫助交易者設定出單的價格與條件，並且會在符合條件時立即遞單到市場上，可以大大節省交易者的計算工作。而我們便可觀察交易者選擇使用此工具的行為，並且探討此工具和最後表現之間的關聯。

代理人基模擬

本研究利用 AIE-DA 平台作為代理人基模擬的實驗環境。AIE-DA 為政治大學人工智慧經濟學研究中心所開發的代理人基雙方喊價市場模擬程式，是以物件導向程式語言 Object Pascal 開發的模擬環境。AIE-DA 內建了許多不同的交易法則或演算法，讓實驗者得以選擇利用不同的交易策略來進行雙方喊價市場的競賽。

AIE-DA 採用的是非連續型的雙方喊價結清機制（discrete double auction），此乃一種「結算所」（clearing house）式的機制——市場會在每位交易者都送出其喊價後，再集中選取一個買方（出價最高的買方）和一個賣方（出價最低的賣方）來配對，若此買方之

喊價高於此賣方之喊價則可進行交易，並以兩者喊價的平均作為成交價格。

在本計畫的代理人基模擬中，我們主要要看的問題是具備學習能力的軟體代理人是否可以在市場交易活動中表現得比其他透過複雜設計或使用解析解的交易策略表現得更好？以及能否找到一個可操作的方法來將計算能力（認知能力）這個變數在計算模型中表現出來？

執是之故，我們選擇使用遺傳程式設計（GP）作為描述具有學習能力的個體的演算法。並且，我們採用個體式的學習法——亦即每個 GP 交易者都有數個策略可供使用，而 GP 交易者會依過去使用的經驗來選擇策略，並且透過重組和創新來更新其策略集合。更進一步，我們將 GP 交易者的策略數目（population size）視為是其認知能力的替代變數。在本研究中，我們為這個變數設立了不同的水準，以觀察他們在面對各種不同的交易對手和市場供需環境中的表現。

而 GP 交易者的競爭對手，則是自經濟學中獻擷取出的十二支交易策略。這些策略有的利用統計方法（貝式法）進行調適，有的則具有相當精巧的設計。GP 交易者將和這些策略進行隨機配對，並且在隨機產生出來的供需環境中進行交易。

真人實驗

本計畫所使用的真人雙方喊價實驗平台，乃是由單機版的代理人基模擬程式 AIE-DA 開發而來。其設計宗旨在於提供一個和單機版程式完全相同的實驗環境，在此環境中不但同樣內建有自經濟學文獻中擷取出的交易策略[1]，而且可允許真人受試者登入參與。因此提供了受試者與軟體交易策略進行交易競賽的環境。

而為了衡量真人受試者的計算能力，我們採用在心理學研究上相當標準的五個工作記憶力測驗（working memory tests）作為受試者心智能力高低的具體數量化指標。這五個測驗項目分別為：

- SS: Sentence Span test

- MU: Memory Updating test

- OS: Operation Span test

- SSTM: Spatial Short-term Memory test

- BDG: Backward Digit Span test

這五項測驗分別針對受試者的數字記憶、運算、空間記憶、語意判斷上加以操作或干

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[1] 事實上，我們在此加入的是在經過模擬實驗後，表現最佳的前七名交易策略，作為和真人同場交易的競爭對手。

擾，來直接或間接的量測出工作記憶的大小。

這五個測驗的結果，經過標準化之後可以得到一個可跨實驗比較的商數。而我們便可將受試者的工作記憶分數與其表現進行相關的分析。

五、結果與討論

本研究計畫所獲得實驗結果與分析，主要將詳述於所附之期刊與會議論文中。在這一節中，我們將簡述結果，並且提供論文發表之相關訊息。

認知能力與期貨交易之表現

在這部分的實驗裡，我們觀察到有使用決策支援系統的使用者相當地少，在五百多位受試者中，僅有十位左右真正的使用了這項工具（真正使用的定義乃視其使用狀況而定，因此不是一個絕對的數字）。由於樣本數量極少，我們得到的有限結論是在前十名的交易者中，有相當的比例是依靠此工具而獲利的。但若針對所有使用此工具的使用者進行討論，卻發現有些使用者雖然有使用，但表現卻仍不盡理想。在這個問題上，由於每位使用者使用的狀況不一（有的僅象徵性的使用，有的是重度依靠），因此在認定上有些許的困難。加之以樣本太小，因此仍有待後續更多樣本的搜集方能加以證明。

那麼，倘若使用與否不足以說明交易者獲利的差異，我們要如何來解讀交易者表現上的差異呢？成功的交易者在交易行為上是否展現出某些特性？於是我們引入了研究複雜網路的方法，試圖來分析市場中交易者的行為模式及其互動後所呈現出的突現現象。於是我們進一步藉由對交易者現金流（cash flow）的記錄資料來析成功交易者的特質，我們發現交易者間的現金流網路是一個具有階層性（hierarchical）、非匹配性（disassortative）、並且具備小世界屬性（small-world）。市場中最成功者與表現最差者同時呈現出相當高的交互作用（high degree）、高中介性（high betweenness）、低群眾係數（low clustering coefficient）、以及低度關係性（low degree-correlation）。

此一研究發現已刊載於 2008 年第六十二卷的 *The European Physical Journal B* 期刊中，題為 Network Topology of an Experimental Futures Exchange。而其中一項相關的實驗結果則是發表於 2006 年第二卷的 *New Mathematics and Natural Computation* 期刊上，題為 Prediction of Bird Flu A(H5N1) Outbreaks in Taiwan by Online Auction: Experimental Results；以及 2009 年第十二卷之 *Advances in Complex Systems*，題為 Emergence of Scale-Free Networks in Markets。

本研究中由於市場規模屬於小規模市場（thin market），因此其所引申出的計量議題，也即將發表於 *Advances in Econometrics* 期刊中，題為 Price Errors from Thin Markets and Their Corrections: Studies Based on Taiwan's Political Futures Markets。而這些發現對於代理人基經濟建模的設計意義，則發表於 2006 年第二卷的 *New*

Mathematics and Natural Computation 期刊，題為 Graph, Networks and ACE。

認知能力與雙方喊價市場中表現之關聯

　　這部分的發現又可分為代理人基計算模型設計以及真人實驗兩部分。在代理人基模擬實驗中，我們發現在創新學習型交易過程上，初期由於缺乏經驗，也不具備任何背景知識，所以 GP 交易者隨機嘗試的結果普遍表現差勁。但初期差勁的表現卻被後來學習的效果所克服。然而 GP 交易者進步的路徑並非呈現線性的上升趨勢。在初期快速的進步後，接著的是較平緩的改善，最後可擊敗其餘的複雜策略，成為獲利最高者。

　　而在認知能力對學習型交易者的影響上，我們發現認知能力較低者會使用極為簡單的策略，而認知能力較高者則會發展出較複雜的策略。令我們感到意外的是，這些使用極其簡單資訊的 GP 交易者，竟然可以擊敗其他複雜多了的交易策略，足以說明學習的結果，並不一定是要發展出理性、或者具備複雜形式的策略，而是適者留存，捨棄不適者的過程。因此，在市場中觀察到簡單的行為，不一定代表在市場中生存不需要太多智慧。

　　以我們的實驗結果而言，GP 在各種不同市場環境中所找到的簡單策略，都是經過一段長時間的摸索而得到的。因此，如果說在我們的市場中極其簡單的法則可以擊敗眾多複雜的交易策略，則不免失之偏頗，並且不能真正反映出智慧行為在市場交易中的價值。而這也意味著，我們需要對人類的「智慧」行為在市場交易行為中的重要性作一翻新的思索。

　　而這部分的發現可作為設計具由異質認知能力的代理人基計算經濟模型的重要參考。這部分的發現，除了已在數個國際會議上發表外，並已被三本會議論文集所接受，分別為 L. Vanneschi, S. Gustafson, A. Moraglio, I. De Falco, 及 M. Ebner 所編之 *Genetic Programming, 12th European Conference, EuroGP 2009*, 題為 Modeling Social Heterogeneity with Genetic Programming in an Artificial Double Auction Market；將由 Springer 所出版之 *Post Proceedings of World Congress on Social Simulation 2008*，題為 The Agent-Based Double Auction Markets: 15 Years On; 以及 *Post Proceedings of the 10th International Workshop on Multi-Agent-Based Simulation (MABS 2009)*，題為 Does Cognitive Capacity Matter in Double Auction Markets?

　　而本計畫對於一個包含異質經濟個體的經濟模型之成果建議，則發表在 2007 年第一百七十七卷的 *Information Sciences* 期刊上，題為 Computationally Intelligent Agents in Economics and Finance。

　　在真人實驗方面，其所呈現出來的結果則有著出不同的面貌。本研究的真人實驗是三個預先選定的特定市場供需下進行，這三個市場都是對稱的市場，但市場中可成交的機會卻有程度上的差異。我們的實驗結果呈現出在第一及第二個市場中，受試者的工作記憶與其獲利表現間無顯著相關，但在第三個市場中則在統計上有顯著的正向關係。這一發現表

示人類決策者的認知能力和其決策結果間的關係，或許要在某些特定情況下才會成立。這部份的研究成果已經在多個實驗經濟或計算經濟學的國際會議上發表，包括在 2009 international Economic Science Association conference（iESA 2009）題為 Agent-Based Modeling of Cognitive Double Auction Market Experiments 的論文，以及在 15th International Conference on Computing in Economics and Finance（CEF 2009）題為 Cognitive Capacity and Economic Decisions: Bidding Behavior in Double Auction Experiments 的論文。並且已撰寫為專書章節，即將於 Y. Kambayashi 所編著，由 Idea Group Publishing 所出版的 *Multi-Agent Applications for Evolutionary Computation and Biologically Inspired Technologies* 一書中刊出，題為 Social Simulation with Both Human Agents and Software Agents: An Investigation into the Impact of Cognitive Capacity on Their Learning Behavior。

六、本計畫論文發表統計

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35th Eastern Economic Association Annual Conference: Conference Report

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1 General Description of the Conference

The Eastern Economic Association holds an annual conference, usually in late February or March, in various cities on the eastern sea board of the United States. Recent conferences have been held in Boston (1999, 2002, 2008), Crystal City, Virginia, Washington, D.C. (2000), New York (2001, 2003, 2005, 2009), Philadelphia (2006) and Washington, D.C. (2004). Building on the tremendous successes at the 2007 and 2008 EEA meetings, the *NYC Computational Economics & Complexity Workshop* (http://nycompworkshop.org/) organized several sessions on *agent-based economics* and related areas. Last year (2008 in Boson), I was invited as a panelist in a round table panel session, the "*The Future of Agent-Based Modeling in Economics.*" (Barr et al., 2008). I, therefore, had a chance to learn this very active and devoted group of researchers on agent-based computational economics. When this year the same event was organized at their headquarters in New York, I decide to attend this event again.

This year, the organized sessions of *the NYC Computational Economics & Complexity Workshop* had a total of 8 sessions, lasting for two days (Feb 27- Feb 28). The research subjects involved are agent-based modeling of contagion phenomena, networks, labor markets, monetary economics, and experimental economics.

2 Market Designs

2.1 Electricity Markets

Hyungna Oh (West Virginia University), co-authored with Timothy Mount (Cornell University), presented the paper "*Using Software Agents to Supplement Tests Conducted by Human Subjects.*" This paper is a typical example of integrating software agents with human agents, and, more interestingly, it was shown in the context of artificial electricity markets.

Why Electricity Markets Matter?   Restructured electricity markets have exhibited unsatisfactory results, most notably in California. Since electricity is a central component of modern economies, market operators and regulatory agencies continually introduce new types of market structures to obtain a more reliable electricity market. Recent introductions include a micro-grid, a capacity market, long-term contracts, demand-side participation, financial transmission rights, and customer's choice of retail services. More recently, smart electricity meters and real-time pricing have also been considered to improve efficiency and mitigate wholesalers market power. Furthermore, deregulation and the unbundling of generation, transmission, and distribution functions provide many choices for a supplier, such as vertical integration, merging with other firms, entering into the new market, or divesting from the market. This variety of choices for generating firms, customers, and market operators implies that electricity markets are not fixed, but continue to change.

Cornell University combined autonomous software agents with experiments using human subjects in analyzing various market options and detecting market power. Oh and Mount tested *whether or not software agents can match the observed behavior of human subjects in laboratory tests of markets*. For this purpose, one set of tests uses four software agents and two human subjects to represent six suppliers in three different electricity market situations: no forward contracts, fixed price forward contracts, and renewable forward contracts. An identical set of tests is also conducted using software agents to represent all of the suppliers. The results show that software agents were able to replicate the behavior of human subjects effectively in the experiments. This indicates that software agents can be used effectively in testing *electricity auctions*, doing additional sensitivity tests, and supplementing results obtained using human subjects.

Their software agents have a backward looking function to learn about the current market from the previous market outcomes. The adaptation involves updating an estimate of the residual demand curve faced by each firm, and this curve is used by the firm to determine the optimum set of offers to maximize expected profits in the next round of the auction. A noticeable result from their work is that under the load uncertainty, agents replicate supply curves that are shaped like hockey sticks. This is exactly the type of behavior observed in deregulated electricity markets.

2.2   Longline Fishery

Run Yu (College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa) co-authored with Ping-Sun Leung (same as above) presented an *agent-based fishery model*. Since its introduction in 1917, Hawaii's longline fishery has developed into a multimillion-dollar sector, harvesting mainly swordfish and tuna for local, mainland U.S., and foreign markets. The continuing existence of Hawaii's longline fishery, however, has been questioned as it poses a danger of accidentally catching protected marine animals such as sea turtles, especially in the swordfish fishery.

In this talk, they presented a prototype agent-based fishery management model for the purpose of simulating the fishing activities of Hawaii's longline vessels, using the strategy of pattern oriented modeling (POM). The model simulates the daily fishing activities of 120 Hawaii longline vessels of diverse characteristics. The prototype model successfully reproduced the spatio-temporal distribution patterns of fishing efforts in Hawaii's

longline fishery, indicating the potential of Agent-based modeling in realistically capture the performance of Hawaii's longline fishery through simulating the behaviors of individual fishermen/vessels. To further test the performance of the prototype model, they used it to evaluate three alternative fishery regulatory policies: (1) no regulation; (2) annual cap of 17 turtle interactions; and (3) close the north central area year round, with respect to their impacts on fishing productivity and by-batch of protected sea turtle. The simulated results are either close to the actual situation or consistent to the previous study results in the literature, indicating that the agent-based fishery management model could realistically capture the diverse behaviors of Hawaii's longline fishermen and predict the responses of the fishery to changes in management regimes.

3 Banking and Finance

3.1 Bank Run

What is the role of inter-bank markets and central banks in coping with banking crises? Pedro Romero (George Mason University) answered this question by developing a sensitivity analysis to the model in Diamond and Dybvig (1983). He implemented an agent-based economic model in Netlogo 4.0.2 to analyze different modifications and extensions to the original. In 36 experiments based on three different versions of the one-bank model the frequency of bank runs dropped from 42% to 17%. This was due to changes in the payoffs structure and *social network effects* whereby depositors go to the bank if at least three of their proximate neighbors went previously. In other experiments with multiple banks interacting in an inter-bank market with banks having the same market share there are no runs escalating to systemic panics. If there is one bank with a market share twice as big as the other ones, a liquidity crisis spreads to more than one bank. On the other hand, when banks cannot interact runs in isolated banks occur with a higher frequency. Finally, *adding a central bank unexpectedly increases the occurrence of bank runs*. Institutional complexity helps to reduce the frequency of bank runs. Hence, decentralized institutional structures perform better than centralized ones.

The design of software agents is very simple in that they do not have sophisticated cognitive capabilities or full information. But they do interact within a microeconomic environment in a dynamic fashion. Yet Romero was able to study the *emergent aggregate results* a la Epstein-Axtell stemming from the agents' interaction. In most of the models presented in this talk; except in the inter-bank market case; he still found the occurrence of bank runs. The models are still very stylized yielding mostly qualitative results. An important step forward is to empirically validate their main implications.

4 Economic Development

Esther Dweck (Institute of Economics of the Federal University of Rio de Janeiro) presented the paper "Demand-Led Growth in a Micro-Macrodynamic Simulation Model." In this talk, she presented a heterodox theoretical framework to discuss some characteristics of developing countries, especially those related to the persistence of balance of payment constraints. The main purpose is to identify characteristics that combined

may create a structural vicious circle imposing an external constraint; a central theme for development economists of the first generation, mainly Raul Prebisch (1901-1986), who reexamined the principle of comparative advantage described by David Ricardo, marking the creation of a new school of economic thought in the late 1940s.

Raul Prebisch Prebisch separated out the purely theoretical aspects of economics from the actual practice of trade and the power structures that underlie trading institutions and agreements. His resulting division of the world into the economic "*centre*", consisting of industrialized nations such as the U.S., and the "*periphery*", consisting of primary producers, remains used to this day. As president of the Central Bank of Argentina he had noticed that during the Great Depression the prices of primary products, such as agricultural goods, fell much more than the prices of manufactured secondary products. However, he and his colleagues were unable to specify the exact mechanism for the difference, beyond noting that supply conditions of primary and secondary goods were different in that while farmers planted the same amount every year regardless of the price they would get, manufacturers were able to reduce or increase capacity to respond to expected changes in demand.

The broader purpose of Dweck's talk is to contribute to the return of discussions regarding a theoretical tool, outside the mainstream, more adequate to address developing countries' issues. She believed that very important complementary references can be drawn by combining the *Evolutionary/Neo-Schumpeterian* and *Post-Keynesian* approaches. Based on the idea that a developing economy has some structural characteristics that create some chronic vicious circles, it is essential to search for a base in economic theory to identify those characteristics and conduct policy to overcome those obstacles. Those characteristics are not the same for every developing country, on the contrary, the last five decades were a period of great divergence within the developing world. The New Development Economics, derived from the neoclassical endogenous growth models, is very limited in dealing with this subject. She tried to show that the main contributions come from outside the mainstream economics, and that a combination of those can be relevant for an alternative approach on economic development. These contributions allow a better comprehension of the debate, and help to strengthen the arguments for policy intervention.

5 Organization and Production

5.1 Modularity and Peer Production

Daniel Neilson (PhD student, Department of Economics, Columbia University) presented the paper "Peer Production, Division of Labor, and Project Modularity." For people who have read the book *The Wealth of Networks: How Social Production Transforms Markets and Freedom* by Yochai Benkler (Benkler, 2006) must agree that the economic significance of peer production cannot be ignored. While much energy has been devoted to understanding the operation of markets, as well as to the working of firms, the coordination mechanisms of peer production, such as Wikipedia and open-source software projects, are not as well understood.

In his talk, Neilson made use of a simple theoretical model, approached first analytically and then using simulation, to make several specific points about *modular peer production*. First, in the simplest of frameworks, he show the benefits of choosing more modularized over less modularized project designs. He extended this in a natural way to a setting that incorporates the costs to modularization as well as the benefits, and show that the optimal modularization of a project with multiple stages of production is one that shares work evenly between the stages. This is the main result of the analytical portion of his presentation. Implementing a simulation of the model, he considered collaborative projects and the organization of participants into hierarchical production teams. He showed that different shapes of hierarchy are better choices under different circumstances.

5.2 Division of Labor

Roger McCain (Department of Economics and International Business, Drexel University) presented the paper "Computational Economics of Adam Smith: Division of Labor as a Computational Object."Multi-agent simulation seems a natural way to study division of labor. However, division of labor requires groups or organizations within which the division takes place, and implies interactive decisions and learning processes, all of which can be modeled or represented in different ways. In his talk, learning and coalition formation have been simulated as processes in the nature of evolutionary computation. The preliminary simulations reported here suggest that a coherent pattern of production and valuation can emerge in such a simulation, provided that coalition formation is somewhat pessimistic.

6 Labor Market

6.1 Is There a Natural Distribution of Income?

Amr Ragab (The New School for Social Research) presented the paper "An Agent-Based Model of Statistical Equilibrium in the Labor Market." Regularities in income distribution patterns have been observed by economists and many attempts were made to try to characterize this distribution. Shaikh and Ragab (2007) showed a rather strikingly strong correlation between the value of the 80% percentiles income share and the Gini coefficient of for the entire distribution. Shaikh and Ragab (2007) studied this relation across a wide spectrum of economies and times. The robustness of this relationship strongly suggests that income distribution could be governed by some law of statistical equilibrium that might fluctuate due to social and historical factors but will always in the long run divert back to this seemingly "natural" distribution of income.

Dragulescu and Yakovenko (2001) provide very strong evidence that the distribution of wage income follows an exponential distribution. Dragulescu and Yakovenko quickly realize that the exponential distribution is also the distribution of temperature in a gas at maximum entropy. How the behavior of gas molecules colliding and exchanging temperature is an equalization/de-equalization process similar to that that happens between workers on a labor market in a capitalist economy? In his talk, Ragab tried to reduce

the gap between the two worlds by proposing an agent-based model with labor market-based behavioral equations for the workers in the model that will produce an exponential distribution. He started by reviewing the models proposed so far by the econophysicist group and the issues with the existing models so far.

7   Tool Development for Agent-Based Modeling

Pietro Terna (Department of Economics and Public Finance, University of Torino) presented the paper "Imaginary or Actual Artificial Worlds Using a New Tool in the ABM Perspective." He proposed Swarm-Like Agent Protocol in Python (SLAPP) as a simplified application of the original Swarm protocol, choosing Python as a simultaneously simple and complete object-oriented framework. With SLAPP he developed two test models in the Agent-Based Models (ABM) perspective, building both an artificial world related to an imaginary situation with stylized chameleons and an artificial world related to the actual important issue of interbank payment and liquidity.

There are three promising lines for future developments:

- In terms of SLAPP, the development of the capability of directly probing each agent, the graphical representation of spatial dynamics and of social networks links, and the simplification of the schedule code for event dynamic.

- In terms of chameleons, the introduction of communication capabilities, mainly via information left in the space, to search for the emergence of social coordination and of social capital.

- In terms of the payment system, applying also in this case the reinforcement learning technique, the introduction of a market maker, i.e., a subject continuously asking and bidding a price for selling and buying money, with a spread, assuring liquidity to the market and developing a pricing capability aimed at the containment of liquidity crisis.

8   Acknowledgements

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10th International Workshop on Multi-Agent-Based Simulation (MABS 2009): Conference Report

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1 General Description of the Conference

1.1 Multi-Agent Based Simulation

Multi-Agent Based Simulation (MABS) is an inter-disciplinary area which brings together researchers active within the multi-agent systems (MAS) community and the agent-based social simulation (ABSS) community. The focus of MAS is on the solution of complex engineering problems related to the construction, deployment and efficient operation of agent-based systems, while the focus of ABSS is on simulating and synthesizing social behaviors in order to understand real social systems (human, animal and even electronic) via the development and testing of new theories.

As evidenced at previous MABS workshops, the MAS and ABSS communities have much to learn from each other. For example, the MAS community has developed agent-based systems that employ sophisticated and elaborated mechanisms (i.e., rich internal models) to solve complex problems, but these techniques are also useful for addressing sociological issues of cooperation, trust and power hierarchies from the social science viewpoint. In constant, the ABSS community has studied and developed techniques and models for real world societies such as companies or economy and they are tested and validated using experimental data, but these models are also useful for real world applications from the engineering viewpoint. This suggests that the communication between MAS and ABSS communities has a potential of deriving methods that overcome their weak points each other.

To promote these cross-influence, the MABS workshop focuses on both the ideas coming from *computer science* as a new technology to provide insights into ABSS community and the ideas coming from *social sciences* as new metaphors to provide insights into MAS community. For this purpose, the workshop provides a forum for social scientists, agent researchers and developers and simulation researchers to assess the current state of the art in the modelling and simulation of MABS, identify where existing approaches can be successfully applied, learn about new approaches and explore future research challenges.

1.2 This Tenth Event

The Multi-Agent-Based Simulation (MABS) workshop is the tenth of a series than began in 1998. This year is held at European Conference Center, Budapest, Hungary, May 11-12. Its scientific focus lies in the confluence of *social sciences* and *multi-agent systems*, with a strong applicational/empirical vein, and its emphasis is stressed on

1. *exploratory agent based simulation* as a principled way of undertaking scientific research in the social sciences and

2. using social theories as an inspiration to new frameworks and developments in multi-agent systems.

The excellent quality level of this workshop has been recognised since its inception, and so its proceedings have always been published by Springer-Verlag, in the Lecture Notes series.

1.3 Submission and Acceptance

This year the workshop has received more than 40 papers. Each paper was reviewed by four referees. In the end, only 16 papers have been accepted. Not only was our submission *"Does Cognitive Capacity Matter in Double Auction Markets?"* accepted, we also benefited very much from the four referee reports. Among the four referee reports, one is negative (rejection), the other three are all positive (one weak acceptance, one acceptance, and one strong acceptance).

1.4 Structure of the Workshop

The 2-day workshop is composed of six sessions, namely,

- Session 1: Simulation of socio-economic behaviors

- Session 2: Representations for planning and decision-making

- Session 3: Trust and Reputation

- Session 4: Environmental Modeling

- Session 5: Self-organizing Behaviors

- Session 6: Data-driven Simulations

2 Simulation of Socio-Economic Behaviors

The three papers presented in Session 1 are all addressing some issues interesting me. The first paper actually addresses a very fundamental question, i.e., the comparison of agent-based simulations with its main alternatives, *system dynamics*. Redha Cherif and Paul Davidsson (Blekinge Institute of Technology, Sweden) presented one of the first actual applications of Multi Agent-Based Simulation (MABS) to the field of *software process*

simulation modelling (SPSM). Although there are some recent attempts to do this, they argued that those fail to take full advantage of the *agency paradigm*. Their model of the software development process integrates individual-level performance, cognition and artifact quality models in a common simulation framework. In addition, their framework allows the implementation of both MABS and System Dynamics (SD) simulators using the same basic models. As SD is the dominating approach within SPSM, they were able to make relevant and unique comparisons between it and MABS. This enabled them to uncover quite interesting properties of these approaches, e.g., that MABS reflects the problem domain more realistically than SD.

2.1 Agent-Based Models of Networks in Supply and Production

Rodolfo Garcia-Flores and his team (CSIRO Mathematical and Information Sciences, Australia) presented an agent-based framework for assessing the cost of committal search in supply networks. The common assumption of unbounded rationality overlooks the facts that decision makers hold beliefs that influence their choices, and that agreement search between agents with conflicting interests is in itself a costly process. As a consequence, *the actual cost of negotiation* is seldom considered in optimization literature. The aim of their paper is to contribute to the development of decision methods that distinguish between the costs of intra-agent (*deliberative*) and inter-agent (*committal*) searches of information by using a *behaviour model* produced by optimizing agents' profit subject to the Cobb-Douglas production function. They proposed and tested *a computational model of rent-seeking, haggling agents* for explicitly assessing *the cost of committal search*. Simulation experiments show that the strategic value of good initial price estimates is higher when these estimates are very close to the actual equilibrium prices, and that agreements may be reached quicker by more selfish agents.

The dynamics of production networks is a complex and still poorly understood phenomenon. This complexity arises from the large number of heterogeneous actors involved and from the spatial distribution and interdependence of these actors. Hamichi and his team (University of Paris 6) investigated this phenomenon using a multi-agent simulation approach, considering each production firm as an agent. They have designed and implemented a Multiagent System (MAS) and investigated the dynamics of the production system, starting with very simple rules of exchange between customers and suppliers. They used adaptive agents taking investment decisions according to their business efficiency. They adapt their prices in order to be competitive and get larger market share. Also, they adapt their business relations (suppliers list) in order to reduce costs of inputs and get orders satisfied. The agent proactivity, based on very simple decision mechanisms at a micro level, leads to the emergence of meta-stable business clusters and supply chains at the macro level of the global production system.

3 Trust and Reputation

Autonomous agents require *trust* and *reputation* concepts in order to identify *communities* of agents with which to interact *reliably* in ways analogous to humans. Agent societies are invariably heterogeneous, with multiple decision making policies and actions governing their behaviour. Through the introduction of *naive agents*, Tony White (Carleton

University, Canada) shows empirically that while learning agents can identify malicious agents through direct interaction, naive agents compromise utility through their inability to discern malicious agents. Moreover, the impact of the proportion of naive agents on the society is analyzed. White demonstrates that here is a need for witness interaction trust to detect naive agents in addition to the need for direct interaction trust to detect malicious agents. By proposing a set of policies, the paper demonstrates how learning agents can isolate themselves from naive and malicious agents.

David Hume delivered an informal theory of how humans managed their way from a rather poor life in small groups to comparatively big wealth based on division of labor in large groups of people that are distant from each other (Hume, 2007). The dynamic is driven by two antagonistic forces: on the one hand specialization entails incentives for division of labour but on the other hand the interaction structure of exchange regimes is that of a moral dilemma. Oliver Will (University of Bayreuth, Germany) presented an agent-based model that formalizes important elements of Hume's theory. The main concepts that capture Hume's ideas are described and first results are presented.

4   Environmental Modeling

Quantifying cumulative environmental impacts (cumulative effects) is challenging due to complex dynamics of natural and human systems interacting. Cumulative effects in linked social-ecological systems are examples of emergent properties in complex systems, which arise from interactions between *multiple users*. Scott Heckbert (CSIRO, Australia) and his team present a multi-agent-based simulation model quantifying cumulative effects in natural resource management, with focus on the interaction of *forestry* and *hunting*. *Agents are calibrated from multiple stated and revealed preference studies of Canadian hunters*. Simulation scenarios explore moose population sustainability under various *access management policies* and with different *hunter preference parameter configurations*. Contrary to the intent of access management, earlier road decommissioning is found to negatively impact overall sustainability of game populations due to cumulative effects of aggregate hunter behaviour. Altering agents preferences for travel cost, game populations, and hunter congestion result in dramatically different spatial outcomes. Certain preference parameter settings create resonance between hunting pressure and game population growth, forming self-organized and persistent spatial resource use patterns.

Understanding the core-periphery dynamic between urban centers and surrounding peripheral communities may be key to understanding sustainability in coming years. Part of this dynamic is the levels of collaborative behaviors in core and peripheral communities. Collaborative behavior has been shown to be a result of repeated interaction between members, which can be a result of community size and levels of interaction between communities. These may be difficult variables to directly measure in many populations. Social network structures associated with collaborative behavior may provide an alternate way to assess levels of collaborative behavior in populations. In his talk, Paul Box (CSIRO, Australia) reproduces a game theory study that examined relative levels of cooperative behavior in a core-periphery setting, and examine associated network measures that are associated with those behaviors.

5   Self-Organizing Behaviors

Ant robots have very low computational power and limited memory. They communicate by leaving pheromones in the environment. In order to create a cooperative intelligent behavior, ants may need to get together; however, they may not know the locations of other ants. Asaf Shilon (Bar Ilan University, Israel) defines the ant meeting problem of bringing two ants to a common position in finite time. He introduces three algorithms (all equivalent to finite state machines) that solve this problem for two ants by simulating a bidirectional breadth-first search in different environment settings. A basic algorithm for a grid with no obstacles, an algorithm for a grid with finite rectangular obstacles and a general algorithm that handles all types of obstacles. He provides detailed discussion on the different attributes, size of pheromone required, and the performance of these algorithms.

Existing models of group behavior, in a variety of fields, leave many open challenges. In particular, existing models often focus only on a specific phenomenon (e.g. flocking, pedestrian movement), and thus must be switched depending on the goals of the simulation. In contrast, Natalie Fridman (Bar Ilan University, Israel) investigates a general cognitive model of simulating group behaviors, based on Festinger's *Social Comparison Theory* (SCT), a prominent social psychology theory. In previous work, she has shown that SCT covers a variety of pedestrian movement phenomena. In this talk she presents evidence for SCTs generality by describing the use of the SCT model (using the Soar cognitive architecture) in generation of imitational behavior in loosely-coupled groups. Since the imitational behavior does not have clear standards of evaluation, she proposes a method for such evaluation. Based on experiments with human subjects, she shows that SCT generates behavior more in-tune with human crowd behavior.

6   Data-Driven Simulations

Samer Hassan (Universidad Complutense de Madrid, Spain) presents an agent based simulation model dealing with the evolution of social values in a 20 year period of the Spanish society. Surveys are taken as input to build the model by following a data-driven approach. This has been formalised in a methodology for introducing micro-simulation techniques and importing data from several sources. It handles thousands of heterogeneous agents, which have a life cycle, reproduction patterns and complex social relationship dynamics. Its output is consistent with respect to the ideological, religious and demographic parameters observed in real world surveys. Moreover, several extension modules were designed: fuzzy logic for a smoother behaviour; natural language biographies generation; data mining for pattern finding. Thus, **Mentat** is proposed as a framework for exploring complexity at different levels in the social process.

Agent based models (ABM) and cellular automata (CA) micro-scale modeling have found abundant application in the area of urban land use and transport planning. These platforms enable a rich spatial representation of residential behavior. Scott Heckbert (CSIRO, Australia) presents an urban ABM that deliberately emphasizes a sparse set of rules that influence agents settlement decisions which interact with detailed spatial data on the geography and climate of a city region. Preliminary results are compared with

historical data (1851 to 2001) of the urban growth of the City of Melbourne, the major urbanized area of the State of Victoria, Australia. He discusses potential extensions to the model and its value as an exploratory device for different transport and climate change scenarios.

7   What Do We Learn? Comments to Our Work

Some useful comments received from the referees are the following.

- While the focus of our paper is very much on the positive relation between cognitive capacity and earning performance in the double auction markets. Referee one draws our attention to literature on minority games which shows the opposite, "*more is less*". Particular, he (she) provides us two papers to look, namely, Takashina and Watanabe (1996) and Savit, Manuca and Riolo (1999).

- Referee one also indicates the possibility of diminishing marginal productivity of intelligence by suggesting a log curve.

- It is always a question on how we justify the use of population size to characterize agents' intelligence by population size.

- In this paper, we consider population size as an software counterpart of human's short-term working memory capacity. Referee 2 questions us on this restriction. He (she) particular questioned us the exclusion of the long-term memory capacity, and hence the possible integration of both short-term and long-term memory.

- Referee 3 brought out the scalable issue. How the size of the agent-based models would affect the results is an issue recent drawing attention from the community. In economics, this size has been considered as an important variable in many different contexts, such as the *core convergence theorem* in the general equilibrium analysis. The referee here is asking whether the superior performance of the GP player can sustain when he is placed in a more competitive market composing many more players with different strategies. This issue may deserves some thoughts on it. It is equivalent to a test of the intelligence-irrelevancy hypothesis in a *large economy*. We can test it using both human agents and software agents.

As to the significance of our paper, the following is directed cited from the referee reports.

- ...it also helps to draw parallels between human intelligence and how it can be modelled in artificial agents. (Referee 2)

- Very good paper, ideas are interesting, the approach is not completely new but perfectly relevant and the question is clear and well oriented, results are very interesting. (Referee 4)

8   Achievable Documents

- Proceedings (Electronic Version in UBS)

9 Acknowledgements

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