Joining the Revolution: Executive Functions and the Transition to the Market

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Abstract

This study looks at the importance of cognitive ability, measured using executive functions (EF)s, in a producer's willingness to adopt a new market activity. Specifically, this study looks at agricultural households' transitions into raising cattle and thus joining the 'livestock revolution' in the northern uplands of Laos. Additionally, this study looks at how what role these EFs may have in production once a producer has entered the market. These questions are answered using both a tobit model as well as a Heckman selection model to account for non-cattle producing households in the sample. These models are used on primary-collected data of over 700 households in a two-year period. Results indicate that EFs, specifically cognitive flexibility and fluid intelligence, play an important role in producers' decisions to enter a market but less so in their productivity once they have entered.

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Introduction

There has long been an interest in economics in better understanding what explains the expansion of the production possibilities frontier, leading to higher productivity and, in some cases, a pathway out of poverty. Schultz (1964), states that there are three ways for traditional producers to increase production possibilities but argues that the only viable option is for producers to change the nature of factor inputs – i.e. replace some or all traditional factor inputs with new ones. Schultz's description for increasing the production possibilities frontier matches well with the management characteristics attributed to one particular group of people, the entrepreneur. But what makes an entrepreneur? In his classical definition, Schumpeter (1947) define the entrepreneur as someone who either does new things or does old things in a new way, whose activity plays a central role in driving economic booms and busts.

Although much of empirical work that has addressed the importance of entrepreneurship has emphasized the importance of material constraints to innovation, and associated market failures, there has been an increased interest in the behavioral specificities of entrepreneurship (Astebro, Herz et al. (2014). This renewed attention naturally links with earlier work on entrepreneurship in economics, particularly the perceived notion that entrepreneurship should be equated with investment under risk, an idea that was first challenged by Knight (1921). Knight argued that under this definition the entrepreneur would not require any particular skills for success, and it is inconceivable that higher rents could be earned by entrepreneurs simply because the entrepreneurs were willing to take risks. It must be that it cannot be willingness to take risks alone that makes a successful entrepreneur and later work focused on the psychological traits to the entrepreneur such as the "need for achievement" (McClelland 1961) and uniquely "modern" personality traits (Inkeles 1975). More recently, and along these lines, (Man 2001) defined several key clusters of entrepreneurial competences, two of which, problem-solving and organization skills, have received considerable attention in the field of cognitive psychology.

This study examines the importance of cognitive function in shaping the "ability to do new things, or old things in new ways". We measure cognitive function using the concept of executive functions (EFs) that the cognitive psychology literature defines as the top-down mental processes that control an individual's attention, dictates their ability to use information or suppress instinctive responses when those responses are not optimal (Miller and Cohen 2001, Espy 2004, Burgess and Simons 2005). EFs are crucial in deliberate activity and include different constructs that have received increasing attention in understanding economic behavior. These include fluid intelligence (synonymous with reasoning and problem-solving) and cognitive planning, both of which build from the core EFs, inhibitory control, working memory, and cognitive flexibility. For a review of executive functions in the psychology literature, see Diamond (2013). The potential importance of differences in EFs in explaining poverty persistence was recently reviewed in (Dean, Schilbach et al. 2019), who highlight its potential importance in the process of technology adoption as agents must be able to see themselves in 'other states of the world', learn about the new technologies, and predict potential costs and benefits of new technology with some degree of accuracy. [1]

There have been efforts to incorporate psychological variables into economic models beyond just EFs. A detailed review of the role of personality traits in economic models is presented by Borghans, Duckworth et al. (2008) and by Almlund, Duckworth et al. (2011). In most of this work, psychological variables such as EFs enter economic models by shaping an agent's preferences, constraints, and expectations (Almlund, Duckworth et al. 2011). One example from Bowles, Gintis et al. (2001), showed that cognitive ability affected earnings through enhanced productivity. Another example is an approach used by Heckman, Stixrud et al. (2006) that used the Roy model (Roy 1951) to introduce cognitive and personality traits as endowments for individual agents. The personality traits (including cognitive traits) determine choices and other factors that affect productivity skills. In Heckman, Stixrud et al. (2006), the productive function for each agent was presented as, $P_j = \phi_j(\theta, e_j)$ where productivity for task j, P_j, depends on each agent's traits, θ, and the effort that the individual expends on each task, e_j.

The idea of cognitive ability and EFs from psychology are still largely unexplored in the economics literature. However, consideration of what these concepts mean in psychology can be

[1] A review of EFs is presented in appendix 1.

translated to economics.[2] For example, agents with higher levels of cognitive flexibility are likely to have different preferences and constraints than agents with lower levels. Cognitive flexibility allows agents to learn new rules more quickly, lowering the cost of switching to something new (e.g. technology adoption). Furthermore, agents with higher levels of cognitive flexibility can also task switch more easily, allowing them to have more diverse production activities than agents with lower abilities to task switch and thus different feasible sets. One way to think of the different levels EFs across producers is as variations in managerial ability. Management has long been recognized as an important input for production but the quantification of its importance was often “excluded since there [was] no satisfactory index of inputs for this factor" (Tintner and Brownlee 1944).

While still sparse, there are some empirical studies done in economics using EF on different economic outcomes. Of the different EFs, inhibitory control has received most of the attention, and has been shown to matter for borrowing and savings (Ashraf, Karlan et al. 2006), consumption (Gruber and Köszegi 2001, Giné, Karlan et al. 2010), as well as productivity (Ariely and Wertenbroch 2002, Kaur, Kremer et al. 2015). Additionally, the effect of attention on technology adoption has received some attention (Bennear, Tarozzi et al. 2013, Drexler, Fischer et al. 2014, Hanna, Mullainathan et al. 2014), as well as the role effect of memory on savings (Karlan, Osei et al. 2014) and health outcomes (Haynes, Ackloo et al. 2008, Vervloet, Linn et al. 2012). Cognitive ability has long been hypothesized to matter to optimization behavior driven by cognitive ability (Andersson, Holm et al. 2016), predicting higher incomes and wages (Murnane, Willett et al. 1995), as well as higher job performance (Bishop 1991). Finally, cognitive flexibility being important for innovation and creativity (Jaušovec 1991, Runco and Okuda 1991, Jaušovec 1994, Chi 1997). Other EFs have received much less attention, although their importance is not necessarily negligible. For example, working memory may affect a variety of behaviors such as technology adoption or migration decisions (Dean, Schilbach et al. 2019).

One major limitation of this growing literature is its isolated discussion of one EF at the time, which seems to go against the very definition of some of these concepts in which EFs are

[2] How EFs enter economic decision making is discussed in more detail in appendix 1.

largely intertwined and build off of each other (Diamond 2013). This may be in part because although these studies have used the language of psychology, they have formalized it and understand it in a different way. Additionally, it is easier to build a model of self-control rather than a model of self-control + memory + attention + flexibility + planning + fluid intelligence.

This study uses the combination of all EFs as managerial ability of an agent, inclusive of entrepreneurial ability. This study proposes that EFs are likely to play an important role in a producer's willingness to adopt a new market activity, or as Schumpeter (1947) says, "try new things". If so, EFs will be important factors in explaining a producer's willingness to enter a new market activity (e.g. cattle) and diversify their livelihoods. This study adds to the literature in several ways. To begin, this study uses a unique and rich dataset that is comprised of data from psychological tasks performed in respondent's homes, as well as data on production decisions. This data is unique, robust psychological data is rarely (if ever) paired with production data, especially from a low-income country. Furthermore, there are no studies to date that use such a rich dataset to investigate production decisions and producer's choice to enter new markets and diversify livelihoods.

The remainder of this papers proceeds as follows: the next section presents the context, data, and methods for this study followed by results and discussion. Our analysis suggests that EFs, particularly cognitive flexibility and fluid intelligence do matter in producer's willingness to enter into (and succeed in) the new market activity of raising cattle. Finally, we conclude with some reflections on the potential policy implications of these findings.

Context and data

Our data comes from rural areas in the north of Laos. As in other parts of Asia, this is a region that is living through what Delgado, Rosegrant et al. (2001) call the 'livestock revolution', the global change in agriculture driven by increased demand for livestock products, itself fueled by population growth, urbanization, and increased incomes in low-income countries.[3] Laos is

[3] FAOSTAT data supports the conclusion that similar trends are at play in Laos, where bovine (cattle and buffalo) meat production has increased nearly fivefold between 1980 and 2013 (from 9,930 tonnes to 49,371 tonnes). Stür,

well placed to participate in this revolution, given it comparative advantage in ruminant production compared to their neighbors (Stür, Gray et al. 2002) and its proximity to large markets (China, but also Vietnam), making cattle production a growing income opportunity in Laos, particularly in the uplands, where topography makes land suitable for cattle production, forest, and little else. See also Phonvisay, Vanhnalat et al. (2016) for a recent overview of cattle industry in Laos and the importance of trade in live animals between Laos and neighboring countries.

Contrasting this new activity (or this old activity produced under very different conditions), the main agricultural activity among many households in our survey is rice, particularly upland rice.[4] In contrast to cattle, mostly raised for sale, rice is mostly grown for household consumption and, in the case of upland rice, as a low-input system that relies on traditional rice varieties and little or no use of inorganic fertilizers (Schiller 2006).[5] In the absence of inorganic fertilizers, soil fertility is managed through periods of fallow, followed by slash-and-burn (Roder, Phengchanh et al. 1995, Pandey and Van Minh 1998).

These two distinct production activities could be classified as what Schultz (1964) called traditional (rice, mostly for household consumption and local trade) and non-traditional (cattle, increasingly for market sales, including international markets).[6] When considering these two different activities, Efs are anticipated to be more important in the non-traditional activity. Largely because the region of the brain where EFs are controlled, the lateral prefrontal cortex, is necessary when learning something new (Diamond 2013) but play a lesser role when new activities are already learned. The primary interest of this study is on raising cattle, the non-traditional, new market activity, however, similar analyses were conducted on the traditional activity of growing rice and those results are in the Appendix.

Gray et al. (2002) state the demand for meat had grown consistently in Laos as well as the rest of Southeast Asia and the trend was likely to continue.

[4] Rice in Laos is cultivated in one of three agroecosystems – upland, irrigated lowland, and rainfed lowland (Schiller 2006). Upland rice is the dominant ecosystem in northern Laos, while irrigated lowland predominates along more fertile areas near the Mekong.

[5] Until the mid-1990's, inorganic fertilizers were not commonly used in Laos (Schiller 2006). Since then, inorganic fertilizer use has increased, but primarily in lowland rice production and especially near the Mekong River (Schiller 2006).

[6] Cattle still also functions as savings for households in addition to being raised for the market.

Data for this study were collected as part of a household survey in two provinces in northern Laos, Luang Prabang and Xiangkhuang. In total, 864 households, in 72 villages, were interviewed over two years (2017 and 2018). Variables of interest that were collected included executive functions (inhibitory control, working memory, cognitive flexibility, intelligence and cognitive planning), rice production, cattle production, input use and other socio-economic and environmental control variables. Due to missing values of some variables, analysis was conducted on the decisions of a sample of 714 unique households in 2017 and 711 unique households in 2018.

The relative importance of these activities is presented in Table 1. Although we only have data for two years, the data is suggestive of a larger transition in this area: a movement away from specialization in rice (the traditional activity), and into a diversified production system of both activities or a specialization in cattle production (the new market activity), with complete abandonment of the subsistence crop.

Table 1. Production system type by year

	2017	2018	Difference
No rice no cattle	25	30	5
Rice only production	170	133	-37
Diversified production	487	498	11
Cattle only production	32	50	18
Total	714	711	-3

We explore the determinants of these changes, and the potential roles of cognitive functioning, by focusing sequentially on the choice of production system (subsistence vs market) and then on the production function estimates conditional on this selection. Descriptive statistics for the variables used in the selection and production models are presented in Table 2, in which we distinguish between types of production systems: specialized and subsistence-orientated (rice only), diversified producers (who combine rice and cattle) and specialized and market-orientated (cattle only).[7]

[7] A fourth regime exists – no cattle and no rice but results for this regime are not presented.

Differences between these groups are also presented in Table 2 with T-tests significance levels. The primary variables of interest in the models are the EFs, measured at the level of the household head. We are particularly interested in the importance of differences in executive functions, which we take as proxies for differences in management. These measures (and their respective measurement instruments) are summarized in Appendix 2.

The most obvious conclusion is that there are significant differences in the executive functions (cognitive flexibility, cognitive planning, fluid intelligence) between those producers who specialize in the traditional activity versus those who adopted a diversified production system and, to a smaller extent, those who specialize in the market activity. In all cases the rice-only producers scored lower in all EF tests. However, there were no significant differences between those producers who specialize in the new market activity and those who adopted diversified producers.

Table 2. Descriptive statistics

	(1) Rice Only			(2) Cattle and Rice			(3) Cattle Only			Difference		
	Mean	St. Dev	n	Mean	St. Dev	n	Mean	St. Dev	n	(1)-(2)	(1)-(3)	(3)-(2)
Household head												
Inhibitory control	0.08	0.1	303	0.08	0.11	995	0.07	0.1	82	-0.002	0.007	-0.01
Working memory	-0.11	1.07	303	0.04	0.96	995	-0.09	0.99	82	-0.15**	-0.02	-0.13
Attention	0.01	1.03	303	0.001	0.99	995	-0.148	0.91	82	0.005	0.14	-0.14
Cognitive flexibility	-0.16	1.03	303	0.08	0.95	995	-0.06	1.12	82	-0.24***	-0.1	-0.14
Cognitive planning	-0.84	1.69	303	-0.45	1.52	995	-0.63	1.67	82	-0.39***	-0.21	-0.18
Fluid intelligence	-0.16	0.91	303	0.07	1.01	995	0.004	1.19	82	-0.23***	-0.17*	-0.07
Schooling	5.33	3.06	303	5.33	2.82	995	6.40	3.42	82	0.001	-1.07***	1.07***
Age	44.1	12.74	303	47.26	12.52	995	47.71	14.08	82	-3.20***	-3.66**	0.45
Male	0.95	0.22	303	0.97	0.17	995	1.00	0.00	82	-0.02	-0.05**	0.03*
Literacy	0.88	0.33	303	0.91	0.29	995	0.96	0.19	82	-0.03**	-0.09**	0.06**
Risk preference	1.96	2.65	303	1.78	2.52	995	1.56	2.27	82	0.18	0.41	-0.22
Time preference	0.16	0.14	303	0.16	0.14	995	0.17	0.14	82	0.001	-0.01	0.01
Household												
Farm size (ha)	3.14	2.71	303	2.97	2.84	995	3.24	3.27	82	0.18	-0.10	0.28
Forest size (ha)	0.45	1.09	303	0.9	1.96	995	0.79	1.66	82	-0.45***	-0.33**	-0.12
Agricultural assets	-0.26	0.83	303	0.2	1.06	995	-0.6	0.46	82	-0.45***	0.34***	-0.79***
Male labor (13-17)	0.32	0.59	303	0.38	0.61	995	0.51	0.71	82	-0.06*	-0.19***	0.13**
Female labor (13-17)	0.38	0.73	303	0.42	0.69	995	0.38	0.66	82	-0.04	-0.002	-0.04
Male labor (18-60)	1.44	0.84	303	1.73	1	995	1.65	0.95	82	-0.29***	-0.21**	-0.08
Female labor (18-60)	1.52	0.77	303	1.71	0.91	995	1.67	1.08	82	-0.19***	-0.15	-0.04
Dependency ratio	1.02	0.75	303	1	0.83	995	1.02	0.64	82	0.01	-0.001	0.01
Village												
Lowland	0.17	0.38	59	0.2	0.41	69	0.09	0.3	32	-0.03	0.08	-0.11*
Upland	0.47	0.5	59	0.46	0.5	69	0.56	0.5	32	0.01	-0.09	0.1
Mixed	0.36	0.48	59	0.33	0.47	69	0.34	0.48	32	0.02	0.01	0.01
Pakxieng district	0.27	0.45	59	0.23	0.43	69	0.41	0.5	32	0.04	-0.14*	0.17**
Viengkham district	0.24	0.43	59	0.28	0.45	69	0.38	0.49	32	-0.04	-0.14*	0.1
Kham district	0.37	0.49	59	0.36	0.48	69	0.16	0.37	32	0.01	0.22**	-0.21**
Phoukhout district	0.12	0.33	59	0.13	0.34	69	0.06	0.25	32	-0.01	0.06	-0.07
LFA policy	0.76	0.43	59	0.77	0.43	69	0.78	0.42	32	-0.01	-0.02	0.01
Dist. to market (km)	8.2	11.28	59	8.07	11.21	69	8.16	12.9	32	0.13	0.05	0.08
Communal grazing (ha)	488.6	849.6	59	495.2	826.4	69	666.5	1034	32	-6.6	-177.9	171.3
Communal forest (ha)	1389.1	2722.6	59	1255.6	2517	69	1108.6	1942.9	32	133.5	280.4	-1476
Village irrigation	0.29	0.46	59	0.28	0.45	69	0.16	0.37	32	0.01	0.13*	-0.12*
Number of ext. visits	4.14	2.66	59	4.48	3.6	69	5.13	4.48	32	-0.34	-0.99*	0.65
Rainy season access	0.75	0.44	59	0.71	0.46	69	0.69	0.47	32	0.04	0.06	-0.02

Note: ‘***’, ‘**’, and ‘*’ are significant at 1%, 5%, and 10% respectively

Methodology

This study is concerned with the effect of executive functions on producers' decisions whether or not to produce cattle and enter the new market activity as well as the role of EFs on the cattle herd size once they have decided to raise cattle. The data used in this study has a panel structure, but because the primary variables of interest, the EFs, are time-invariant, fixed effect models will not be able to individually identify the effects of the EFs. Additionally, production models in this study are censored at zero to distinguish between producers and non-producers, thus violating the assumption of random effects requiring a bivariate normal distribution. As such, production is estimated as a cross-section for the two years of data, providing two snapshots of the transition to the market. This study first estimates selection into raising cattle by using a probit model and then estimates herd sizes using both a tobit model as well as a Heckman (1979) selection model. Both models were specified with a lower limit set at zero:

$$y = \begin{cases} y^* if\ y^* > 0 \\ 0\ if\ y^* \leq 0 \end{cases} \tag{1}$$

Additionally, both the tobit and the Heckman models use probit models for censoring/truncating at zero such that they take their standard forms.

Tobit:

$$prob(y > 0) = \Phi(\boldsymbol{x}'\beta) \tag{2}$$

$$E(y|y > 0) = \boldsymbol{x}'\beta + \alpha\lambda\left(\frac{\boldsymbol{x}'\beta}{\sigma}\right) \tag{3}$$

Heckman:

$$prob(z = 1) = \Phi(\boldsymbol{z}'\gamma) \tag{4}$$

$$E(y|z = 1) = \boldsymbol{x}'\beta + \rho\sigma\hat{\lambda}(\boldsymbol{w}'\gamma) \tag{5}$$

Summary statistics for the explanatory variables used in equations (2) – (5) are presented in Table 2. Independent variables for all of these models include the primary variables of interest, EFs, as well as control variables for environmental and socioeconomic conditions at the levels of household head, household, and village. The independent variables used in each step of the tobit model are restricted to be the same (see Table 4). There is no such restriction for the Heckman model, so the independent variables differ from the first (discrete) stage of the Heckman model (see Table 3) to the second (continuous) stage of the Heckman model (see Table 4).

Results and Discussion

The results of modelling the decision to enter the production of cattle are presented in Table 3. This probit selection model consists of the EFs (variables of interest), as well as controls at the individual and village levels. Individual controls included risk and time preferences. Risk preference was measured following the procedure described by Eckel and Grossman (2003) and time preference was measured using an intertemporal discount rate computed using payments one month and seven months in the future. Risk preference was significant in the selection model in 2018, suggesting that risk aversion increased the probability of producers to select into cattle production for that year. However, risk preference was not significant in 2017. Similarly, time preferences were not significant in either year. With respect to the variables of interest, the executive functions, cognitive flexibility was found to be significant and positive in a producer’s decision to raise cattle in both seasons and fluid intelligence was found to be significant in 2017. In all of these cases, higher levels of cognitive flexibility and fluid intelligence resulted in a higher probability of selecting into cattle production. These EFs were found to be important factors in choosing whether or not to raise cattle (the new market activity) and conversely, none of the EFs were found to be significant in a producer’s decision to grow rice (the traditional activity).

Table 3. Probit results by year

	2017		2018	
	Mean	St. Error	Mean	St. Error
Cognitive planning	0.041	(0.037)	0.041	(0.038)
Fluid intelligence	0.132**	(0.059)	0.077	(0.059)
Inhibitory control	-0.193	(0.516)	0.101	(0.509)
Working memory	-0.038	(0.062)	-0.073	(0.062)
Cognitive flexibility	0.124**	(0.057)	0.098*	(0.058)
Attention	0.056	(0.058)	-0.008	(0.059)
Risk preference	-0.033	(0.021)	-0.040*	(0.022)
Time preference	-0.104	(0.399)	0.142	(0.409)
Schooling	-0.036	(0.023)	-0.037	(0.023)
Age	0.004	(0.005)	0.002	(0.005)
Male	0.802***	(0.270)	0.502*	(0.260)
Literacy	0.240	(0.208)	0.182	(0.208)
Male labor (13-17)	0.197**	(0.098)	0.229**	(0.110)
Female labor (13-17)	0.031	(0.084)	-0.035	(0.093)
Male labor (18-60)	0.312***	(0.075)	0.325***	(0.082)
Female labor (18-60)	0.099	(0.072)	0.052	(0.069)
Dependency Ratio	0.193**	(0.090)	0.189**	(0.091)
LFA policy	0.264	(0.168)	0.238	(0.171)
Distance to market (km)	-0.010*	(0.005)	-0.005	(0.006)
Communal grazing (ha)	0.000***	(0.000)	0.000***	(0.000)
Communal forest (ha)	-0.000***	(0.000)	-0.000***	(0.000)
Village irrigation scheme	0.364**	(0.152)	0.344**	(0.153)
Number of extension visits	0.029*	(0.015)	0.005	(0.015)
Rainy season car access	-0.600***	(0.145)	-0.505***	(0.148)
Mixed ecosystem	-0.625***	(0.179)	-0.423**	(0.185)
Upland ecosystem	-1.127***	(0.198)	-0.915***	(0.201)
Distance to District HQ (km)	0.004	(0.003)	0.003	(0.004)
Constant	-0.452	(0.468)	0.058	(0.474)
Observations	714		711	

Note: '***', '**', and '*' are significant at 1%, 5%, and 10% respectively
Values in parentheses are robust standard errors

Unsurprisingly, the EF tasks (cognitive flexibility and fluid intelligence) were found to be positive and significant in Table 3. As described in Appendix 1, the Berg card sorting task was used to measure cognitive flexibility., This task measures the participants' ability to change perspectives and approaches to a problem in which they can respond to new rules, demands, and priorities (Diamond 2013). Similarly, Raven's progressive matrices were used to measure the participants ability to reason, problem solve, and see patterns and relations among things in which they have no prior experience using both inductive and deductive reasoning (Diamond 2013). Both of these measurements from psychological tests enter an agent's utility function through changes in preferences and expectations in a way that makes them more likely to enter a new livelihood. If an agent is good at solving new problems, or can easily task switch to accommodate multiple activities, the transition into a new and/or diversified production activity will be easier.

Interestingly, Table 3 shows that the effect of fluid intelligence on entering cattle production disappeared from 2017 to 2018 and the effect of cognitive flexibility on entering cattle production lessened in the magnitude of the coefficient as well as the significance level. The coefficients from 2017 to 2018 were significantly different for both fluid intelligence and cognitive flexibility. The change in these values can be explained by a total of 43 households (~6% of sample) that transitioned from not raising cattle in 2017 to raising cattle in 2018. The mean values of fluid intelligence and cognitive flexibility for this transition group was below the average of the established group raising cattle in 2017. For fluid intelligence, these mean values were .075 and -0.231 for the established and transition groups, respectively. Similarly, for cognitive flexibility these mean values were 0.767 and -0.358 for the established and transition groups, respectively. This may indicate that producers with higher fluid intelligence and cognitive flexibility transitioned into raising cattle earlier than their counterparts with lesser scores on these tasks. Figure 1 shows that the average score of cognitive flexibility for cattle growers in our sample declined since 2017.

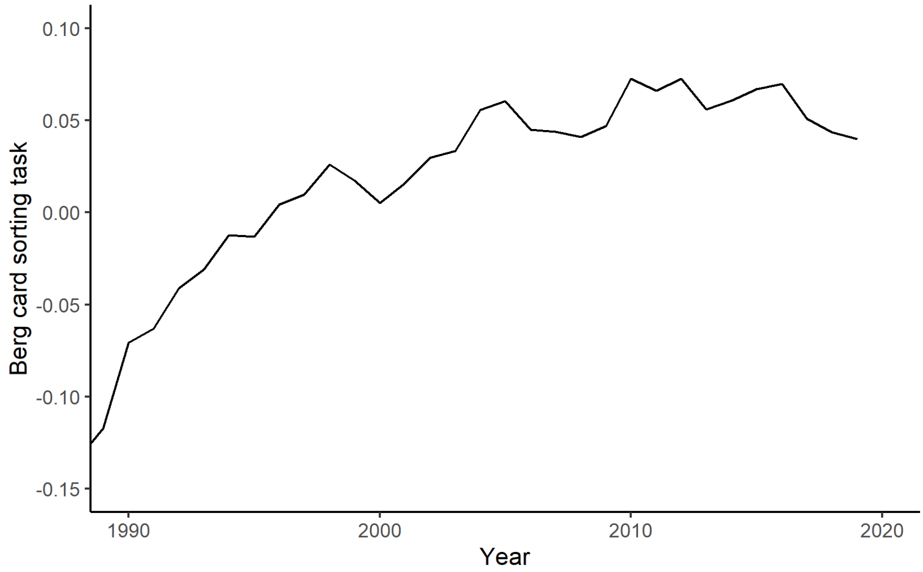

Figure 1. Average of Berg card sorting task by year

Figure 1 shows that through the 1990s, the average cognitive flexibility score of cattle growers in our sample increased by more than three times its initial value. This is substantially more than the increase seen in the two succeeding decades. Phonvisay, Vanhnalat et al. (2016) stated that it was during the 1990s that the Lao Government and international donors recognized the importance of the cattle industry to smallholder farmers and worked towards building capacity in the cattle industry. The large increase in average cognitive flexibility scores seen through the 1990s was likely the result of what Rogers (1995) would call 'early adopters' or 'early majority' entering the market. Early adopters are considered to be from the first 2.5% - 16% of adopters and early majority are considered to be from the first 16% - 50%. However, Figure 2 shows that approximately 17% of our sample were already raising cattle in 1990.

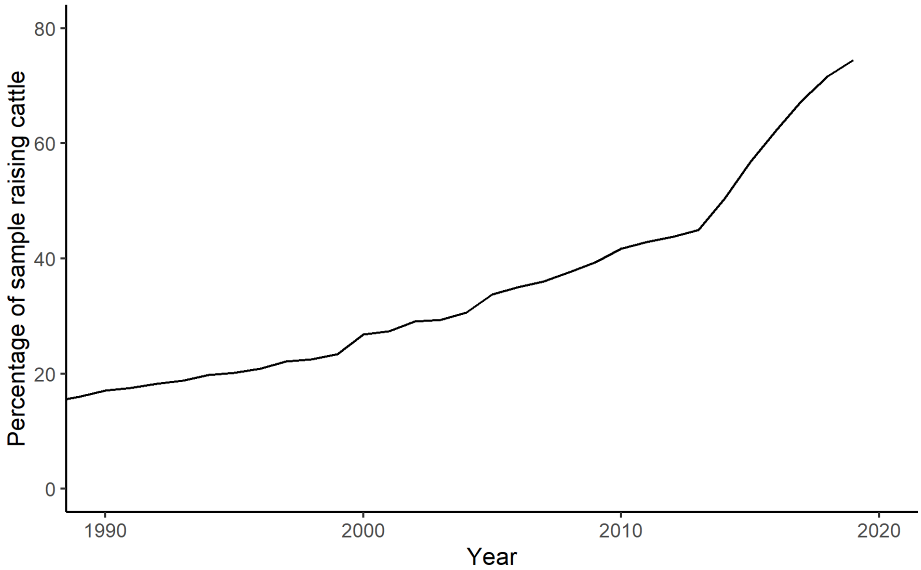

Figure 2: Cumulative density function of population raising cattle

The percentage of our sample raising cattle by year is shown in Figure 2. It is important to consider the multiple functions of cattle in producers' lives – cattle are not only raised for sale to the market, but they also serve as savings for households. The function of cattle for savings can explain why 17% of the sample were already raising cattle in 1990, just prior to the promotion of cattle production by the government in Laos. Since the 1990s, there has been a gradual increase in the percentage of the sample raising cattle (≈1% per annum), with a noticeable uptick from 2014 - 2018, when the percent raising cattle increased by approximately 5% per annum. The resulting 'S' shape of this transition seen in the cumulative density function in Figure 2 is consistent with the 'S' shape from Rogers (1995) diffusion of innovation theory.

Table 4. Heckman Selection and Tobit model for cattle herd size by year

	Heckman				Tobit			
	2017		2018		2017		2018	
	Mean	St. Error	Mean	St. Error	Mean	St. Error	Mean	St. Error
Cognitive planning	0.168	(0.246)	0.117	(0.265)	0.296	(0.238)	0.232	(0.235)
Fluid intelligence	0.246	(0.413)	0.360	(0.384)	0.693^{*}	(0.356)	0.477	(0.351)
Inhibitory control	-1.26	(2.90)	-3.36	(2.99)	-1.32	(3.02)	-1.69	(3.06)
Working memory	0.306	(0.368)	0.382	(0.414)	0.070	(0.393)	0.089	(0.387)
Cognitive flexibility	0.586	(0.457)	0.552	(0.458)	0.89^{**}	(0.394)	0.590	(0.385)
Attention	0.160	(0.359)	0.350	(0.346)	0.391	(0.348)	0.227	(0.361)
Risk preference	0.146	(0.144)	0.153	(0.170)	0.041	(0.146)	0.039	(0.150)
Time preference	2.47	(2.40)	2.521	(2.51)	1.80	(2.49)	1.98	(2.52)
Schooling	0.036	(0.151)	-0.077	(0.168)	-0.165	(0.138)	-0.176	(0.133)
Age	0.091^{***}	(0.030)	0.081^{***}	(0.030)	0.075^{**}	(0.030)	0.063^{**}	(0.030)
Male	-1.67	(2.93)	1.26	(2.42)	2.61	(1.93)	2.12	(1.71)
Literacy	0.012	(1.36)	0.617	(1.36)	1.28	(1.40)	0.918	(1.39)
Farm size (ha)	-0.144	(0.117)	-0.082	(0.119)	-0.268^{*}	(0.140)	-0.169	(0.145)
Forest (ha)	0.417^{**}	(0.167)	0.369^{**}	(0.174)	0.704^{***}	(0.189)	0.64^{***}	(0.215)
Ag asset index	1.89^{***}	(0.457)	1.48^{***}	(0.467)	2.93^{***}	(0.462)	2.36^{***}	(0.454)
Male labor (13-17)	0.374	(0.651)	0.083	(0.785)	0.903	(0.558)	0.600	(0.555)
Female labor (13-17)	0.005	(0.472)	-0.319	(0.545)	0.123	(0.454)	-0.413	(0.520)
Male labor (18-60)	1.39^{*}	(0.737)	1.72^{**}	(0.872)	2.21^{***}	(0.482)	2.17^{***}	(0.482)
Female labor (18-60)	1.18^{***}	(0.432)	1.46^{***}	(0.424)	1.37^{***}	(0.473)	1.44^{***}	(0.495)
Dependency Ratio	0.847	(0.638)	1.34^{*}	(0.706)	1.28^{**}	(0.534)	1.55^{***}	(0.579)
Pakxieng district	3.72^{***}	(1.41)	2.63^{*}	(1.41)	2.27	(1.47)	2.13	(1.41)
Viengkham district	2.78^{**}	(1.25)	2.90^{**}	(1.27)	2.59^{*}	(1.45)	2.56^{*}	(1.50)
Phoukhout district	1.43	(1.26)	1.48	(1.28)	-0.953	(1.53)	-1.32	(1.54)
Number of ext. visits	0.032	(0.116)	-0.037	(0.102)	0.138	(0.104)	0.001	(0.115)
Rainy season car access	-1.58	(1.60)	-2.39	(1.63)	-3.80^{***}	(1.07)	-3.40^{***}	(1.08)
LFA policy	2.98^{**}	(1.20)	2.99^{**}	(1.22)	3.93^{***}	(1.08)	3.67^{***}	(1.10)
Distance to market (km)	0.049	(0.042)	0.078^{**}	(0.039)	-0.022	(0.036)	0.026	(0.035)
Communal grazing (ha)	-0.000	(0.001)	-0.000	(0.001)	0.001^{**}	(0.001)	0.001	(0.001)
Communal forest (ha)	-0.000	(0.000)	-0.000	(0.000)	-0.001^{***}	(0.000)	-0.001^{**}	(0.000)
Village irrigation scheme	-0.510	(1.24)	0.288	(1.32)	0.680	(0.995)	0.912	(0.909)
Distance to District HQ (km)	0.066^{**}	(0.026)	0.066^{**}	(0.026)	0.081^{***}	(0.023)	0.078^{***}	(0.023)
Mixed ecosystem	-0.410	(1.63)	-1.25	(1.51)	-1.66^{*}	(0.976)	-1.37	(0.967)
Upland ecosystem	-5.14^{*}	(2.74)	-6.35^{**}	(2.79)	-6.97^{***}	(1.25)	-6.94^{***}	(1.21)
lambda	0.677	(5.33)	3.81	(6.94)				
Constant	-2.51	(6.07)	-5.80	(5.65)	-8.98^{***}	(3.12)	-7.07^{**}	(3.13)
Observations	714		711		714		711	

Note: '***', '**', and '*' are significant at 1%, 5%, and 10% respectively
Values in parentheses are robust standard errors

There is less evidence to support EFs playing a critical role in cattle herd size as there was for the selection into cattle presented in Table 3. In the case of the Heckman selection model which uses the probit model from Table 3 to estimate the producer's propensity to raise cattle, none of the EFs were found to be significant in the cattle herd size. It was only in the tobit estimation for 2017 that fluid intelligence and cognitive flexibility were found to be significant. However, both fluid intelligence and cognitive function in the tobit model exhibited reductions in the magnitude of the coefficients, and the significance vanished from 2017 to 2018. This effect on cattle herd size may be explained in part by the lower levels of fluid intelligence and cognitive flexibility scores of the group of 46 households that transitioned into raising cattle in 2018 – similar to the effect that was seen in the probit model. However, there are also other more likely reasons that these EFs would play a lesser role in cattle herd size as compared to the selection into cattle. To begin, it is necessary to access the portion of the brain that is responsible for controlling EFs, the lateral prefrontal cortex, when learning something new (Diamond 2013) but once something is no longer new, accessing the lateral prefrontal cortex can be detrimental to performance (Garavan, Kelley et al. 2000, Milham, Banich et al. 2003, Chein and Schneider 2005, Landau, Garavan et al. 2007).[8] For instance, once aspects of caring for cattle (e.g. feeding vaccinating) have become habit, there is no longer an advantage to having higher levels of EFs. Additionally, properly managed production functions in cattle do not necessarily equate to larger herd sizes. As stated by Jarvis (1974), cattle are a capital good that are held by producers until their slaughter value is less than their capital value. As such, there are times that selling for slaughter is optimal to keeping cattle as a capital good – resulting in a smaller herd size.

While there is evidence that EFs matter in the non-traditional new market activity (cattle production), there is no evidence that EFs matter in the traditional activity, (rice production). The results for rice are in Appendix 3 (probit) and Appendix 4 (tobit and Heckman). In the case of the probit model, none of the EFs were significant in producers' decisions to grow rice. Fluid intelligence was significant for the tobit model in 2017, but the coefficient was negative. The

[8] As a practical example, consider the muscle memory used by a professional athlete. Thinking through the mechanics of shooting a basketball or soccer ball can lead to less ideal outcomes as compared to relying on muscle memory.

negative coefficient could indicate that EFs are only important while learning something new and using them for activities that are no longer new may be detrimental to outcomes. Since rice is the traditional crop, EFs were not expected to play an important role in its selection or production.

Conclusions

Using EFs as proxies for differing management capacities, this study shows the importance of EFs, namely, cognitive flexibility and fluid intelligence in transitioning to the market for cattle production in Laos. Producers with higher levels of cognitive flexibility (both years) and fluid intelligence (2017 only) were more likely raise cattle. These results are of interest to researchers working in the cross section of economics and psychology by furthering the understanding of EFs on adoption and transitioning into diversified production systems. Additionally, the results of this study identify that EFs may be constraints to adoption, a finding that is also important for policy makers and other groups as they create development projects in the future. Furthermore, if these constraints are binding, there is evidence that EFs can be improved (Klingberg 2010, Diamond and Lee 2011), one of the most promising examples being through computerized training (Klingberg, Fernell et al. 2005, Holmes, Gathercole et al. 2009, Thorell, Lindqvist et al. 2009, Bergman Nutley, Söderqvist et al. 2011). Strengthening EFs through targeted interventions may relax these constraints and help ensure the success of future development projects.

References

Almlund, M., A. L. Duckworth, J. Heckman and T. Kautz (2011). Personality psychology and economics. Handbook of the Economics of Education, Elsevier. **4:** 1-181.

Anderson, M. C. and B. J. Levy (2009). "Suppressing unwanted memories." Current Directions in Psychological Science **18**(4): 189-194.

Andersson, O., H. J. Holm, J.-R. Tyran and E. Wengström (2016). "Risk aversion relates to cognitive ability: Preferences or Noise?" Journal of the European Economic Association **14**(5): 1129-1154.

Ariely, D. and K. Wertenbroch (2002). "Procrastination, deadlines, and performance: Self-control by precommitment." Psychological science **13**(3): 219-224.

Ashraf, N., D. Karlan and W. Yin (2006). "Tying Odysseus to the mast: Evidence from a commitment savings product in the Philippines." The Quarterly Journal of Economics **121**(2): 635-672.

Astebro, T., H. Herz, R. Nanda and R. A. Weber (2014). "Seeking the roots of entrepreneurship: Insights from behavioral economics." Journal of Economic Perspectives **28**(3): 49-70.

Bennear, L., A. Tarozzi, A. Pfaff, S. Balasubramanya, K. M. Ahmed and A. Van Geen (2013). "Impact of a randomized controlled trial in arsenic risk communication on household water-source choices in Bangladesh." Journal of environmental economics and management **65**(2): 225-240.

Berg, E. A. (1948). "A simple objective technique for measuring flexibility in thinking." The Journal of general psychology **39**(1): 15-22.

Bergman Nutley, S., S. Söderqvist, S. Bryde, L. B. Thorell, K. Humphreys and T. Klingberg (2011). "Gains in fluid intelligence after training non-verbal reasoning in 4-year-old children: A controlled, randomized study." Developmental science **14**(3): 591-601.

Besner, D. and M. Coltheart (1979). "Ideographic and alphabetic processing in skilled reading of English." Neuropsychologia **17**(5): 467-472.

Bishop, J. (1991). Impact of Academic Competencies on Wages, Unemployment & Job Performance. CAHRS Working Paper. Ithica, NY, Center for Advanced Human Resources Studies.

Borghans, L., A. L. Duckworth, J. J. Heckman and B. Ter Weel (2008). "The economics and psychology of personality traits." Journal of human Resources **43**(4): 972-1059.

Bourguignon, F., M. Fournier and M. Gurgand (2007). "Selection bias corrections based on the multinomial logit model: Monte Carlo comparisons." Journal of Economic Surveys **21**(1): 174-205.

Bowles, S., H. Gintis and M. Osborne (2001). "The determinants of earnings: A behavioral approach." Journal of economic literature **39**(4): 1137-1176.

Burgess, P. W. and J. S. Simons (2005). "18 Theories of frontal lobe executive function: clinical applications." The effectiveness of rehabilitation for cognitive deficits: 211.

Canas, J., J. Quesada, A. Antolí and I. Fajardo (2003). "Cognitive flexibility and adaptability to environmental changes in dynamic complex problem-solving tasks." Ergonomics **46**(5): 482-501.

Carlin, D., J. Bonerba, M. Phipps, G. Alexander, M. Shapiro and J. Grafman (2000). "Planning impairments in frontal lobe dementia and frontal lobe lesion patients." Neuropsychologia **38**(5): 655-665.

Chein, J. M. and W. Schneider (2005). "Neuroimaging studies of practice-related change: fMRI and meta-analytic evidence of a domain-general control network for learning." Cognitive Brain Research **25**(3): 607-623.

Chi, M. T. (1997). Creativity: Shifting across ontological categories flexibly. Creative thought: An investigation of conceptual structures and processes. T. B. Ward, S. M. Smith and J. Vaid. Washington DC, US: American Psychological Association**:** 209-234.

Collins, A. and E. Koechlin (2012). "Reasoning, learning, and creativity: frontal lobe function and human decision-making." PLoS biology **10**(3): e1001293.

Conway, A. R., M. J. Kane and R. W. Engle (2003). "Working memory capacity and its relation to general intelligence." Trends in cognitive sciences **7**(12): 547-552.

Corsi, P. M. (1973). Human memory and the medial temporal region of the brain, ProQuest Information & Learning.
Cowan, N., A. M. AuBuchon, A. L. Gilchrist, T. J. Ricker and J. S. Saults (2011). "Age differences in visual working memory capacity: Not based on encoding limitations." Developmental science **14**(5): 1066-1074.
Cowan, N., J. S. Saults and E. M. Elliott (2002). The search for what is fundamental in the development of working memory. Advances in child development and behavior, Elsevier. **29:** 1-49.
Crone, E. A., C. Wendelken, S. Donohue, L. van Leijenhorst and S. A. Bunge (2006). "Neurocognitive development of the ability to manipulate information in working memory." Proceedings of the National Academy of Sciences **103**(24): 9315-9320.
Davidson, M. C., D. Amso, L. C. Anderson and A. Diamond (2006). "Development of cognitive control and executive functions from 4 to 13 years: Evidence from manipulations of memory, inhibition, and task switching." Neuropsychologia **44**(11): 2037-2078.
Dean, E. B., F. Schilbach and H. Schofield (2019). Poverty and Cognitive Function. The Economics of Poverty Traps. C. B. Barrett, M. R. Carter and J.-P. Chavas. Chicago, IL, University of Chicago Press**:** 57.
Delgado, C., M. Rosegrant, H. Steinfeld, S. Ehui and C. Courbois (2001). "Livestock to 2020: The next food revolution." Outlook on Agriculture **30**(1): 27-29.
Diamond, A. (2013). "Executive functions." Annual review of psychology **64**: 135-168.
Diamond, A. and K. Lee (2011). "Interventions shown to aid executive function development in children 4 to 12 years old." Science **333**(6045): 959-964.
Drexler, A., G. Fischer and A. Schoar (2014). "Keeping it simple: Financial literacy and rules of thumb." American Economic Journal: Applied Economics **6**(2): 1-31.
Duncan, J., A. Parr, A. Woolgar, R. Thompson, P. Bright, S. Cox, S. Bishop and I. Nimmo-Smith (2008). "Goal neglect and Spearman's g: competing parts of a complex task." Journal of Experimental Psychology: General **137**(1): 131.
Eckel, C. C. and P. J. Grossman (2003). "Forecasting risk attitudes: An experimental study of actual and forecast risk attitudes of women and men." Virginia Tech Department of Economics Working Paper.
Espy, K. A. (2004). "Using developmental, cognitive, and neuroscience approaches to understand executive control in young children." Developmental Neuropsychology **26**(1): 379-384.
Ferrer, E., B. A. Shaywitz, J. M. Holahan, K. Marchione and S. E. Shaywitz (2010). "Uncoupling of reading and IQ over time: Empirical evidence for a definition of dyslexia." Psychological science **21**(1): 93-101.
Friedman, N. P., A. Miyake, R. P. Corley, S. E. Young, J. C. DeFries and J. K. Hewitt (2006). "Not all executive functions are related to intelligence." Psychological science **17**(2): 172-179.
Garavan, H., D. Kelley, A. Rosen, S. M. Rao and E. A. Stein (2000). "Practice-related functional activation changes in a working memory task." Microscopy research and technique **51**(1): 54-63.
Garon, N., S. E. Bryson and I. M. Smith (2008). "Executive function in preschoolers: a review using an integrative framework." Psychological bulletin **134**(1): 31.
Giné, X., D. Karlan and J. Zinman (2010). "Put your money where your butt is: a commitment contract for smoking cessation." American Economic Journal: Applied Economics **2**(4): 213-235.
Gruber, J. and B. Köszegi (2001). "Is addiction “rational”? Theory and evidence." The Quarterly Journal of Economics **116**(4): 1261-1303.
Hanna, R., S. Mullainathan and J. Schwartzstein (2014). "Learning through noticing: Theory and evidence from a field experiment." The Quarterly Journal of Economics **129**(3): 1311-1353.
Haynes, R., E. Ackloo, N. Sahota, H. McDonald and X. Yao (2008). "Interventions for enhancing medication adherence." The Cochrane database of systematic reviews(2): CD000011.
Heckman, J. J. (1979). "Sample selection bias as a specification error." Econometrica: Journal of the econometric society: 153-161.
Heckman, J. J., J. Stixrud and S. Urzua (2006). "The effects of cognitive and noncognitive abilities on labor market outcomes and social behavior." Journal of Labor economics **24**(3): 411-482.

Henik, A. and J. Tzelgov (1982). "Is three greater than five: The relation between physical and semantic size in comparison tasks." Memory & cognition **10**(4): 389-395.
Holmes, J., S. E. Gathercole and D. L. Dunning (2009). "Adaptive training leads to sustained enhancement of poor working memory in children." Developmental science **12**(4): F9-F15.
Horn, J. L. and R. B. Cattell (1966). "Refinement and test of the theory of fluid and crystallized general intelligences." Journal of educational psychology **57**(5): 253.
Inkeles, A. (1975). "Becoming modern: Individual change in six developing countries." Ethos **3**(2): 323-342.
Jarvis, L. S. (1974). "Cattle as capital goods and ranchers as portfolio managers: an application to the Argentine cattle sector." Journal of Political Economy **82**(3): 489-520.
Jaušovec, N. (1991). "Flexible strategy use: A characteristic of gifted problem solving." Creativity Research Journal **4**(4): 349-366.
Jaušovec, N. (1994). Flexible thinking: An explanation for individual differences in ability, Hampton Press.
Kane, M. J. and R. W. Engle (2002). "The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual-differences perspective." Psychonomic bulletin & review **9**(4): 637-671.
Karlan, D., R. Osei, I. Osei-Akoto and C. Udry (2014). "Agricultural decisions after relaxing credit and risk constraints." The Quarterly Journal of Economics **129**(2): 597-652.
Kaur, S., M. Kremer and S. Mullainathan (2015). "Self-control at work." Journal of Political Economy **123**(6): 1227-1277.
Klingberg, T. (2010). "Training and plasticity of working memory." Trends in cognitive sciences **14**(7): 317-324.
Klingberg, T., E. Fernell, P. J. Olesen, M. Johnson, P. Gustafsson, K. Dahlström, C. G. Gillberg, H. Forssberg and H. Westerberg (2005). "Computerized training of working memory in children with ADHD-a randomized, controlled trial." Journal of the American Academy of Child & Adolescent Psychiatry **44**(2): 177-186.
Knight, F. (1921). "Risk, Uncertainty and Profit."
Kotovsky, K., J. R. Hayes and H. A. Simon (1985). "Why are some problems hard? Evidence from Tower of Hanoi." Cognitive psychology **17**(2): 248-294.
Landau, S. M., H. Garavan, E. H. Schumacher and M. D'Esposito (2007). "Regional specificity and practice: dynamic changes in object and spatial working memory." Brain research **1180**: 78-89.
Lehto, J. E., P. Juujärvi, L. Kooistra and L. Pulkkinen (2003). "Dimensions of executive functioning: Evidence from children." British Journal of Developmental Psychology **21**(1): 59-80.
Luciana, M., H. M. Conklin, C. J. Hooper and R. S. Yarger (2005). "The development of nonverbal working memory and executive control processes in adolescents." Child development **76**(3): 697-712.
Lunt, L., J. Bramham, R. G. Morris, P. R. Bullock, R. P. Selway, K. Xenitidis and A. S. David (2012). "Prefrontal cortex dysfunction and 'jumping to conclusions': bias or deficit?" Journal of Neuropsychology **6**(1): 65-78.
Mackworth, N. H. (1948). "The breakdown of vigilance during prolonged visual search." Quarterly Journal of Experimental Psychology **1**(1): 6-21.
Man, W.-y. T. (2001). Entrepreneurial competencies and the performance of small and medium enterprises in the Hong Kong services sector, The Hong Kong Polytechnic University.
Martin, M. M. and C. M. Anderson (1998). "The cognitive flexibility scale: Three validity studies." Communication Reports **11**(1): 1-9.
Martin, M. M. and R. B. Rubin (1995). "A new measure of cognitive flexibility." Psychological reports **76**(2): 623-626.
McClelland, D. C. (1961). Achieving society, Simon and Schuster.
Milham, M., M. Banich, E. Claus and N. Cohen (2003). "Practice-related effects demonstrate complementary roles of anterior cingulate and prefrontal cortices in attentional control." Neuroimage **18**(2): 483-493.

Miller, E. K. and J. D. Cohen (2001). "An integrative theory of prefrontal cortex function." Annual review of neuroscience **24**(1): 167-202.
Miyake, A., N. P. Friedman, M. J. Emerson, A. H. Witzki, A. Howerter and T. D. Wager (2000). "The unity and diversity of executive functions and their contributions to complex “frontal lobe” tasks: A latent variable analysis." Cognitive psychology **41**(1): 49-100.
Moffitt, T. E., L. Arseneault, D. Belsky, N. Dickson, R. J. Hancox, H. Harrington, R. Houts, R. Poulton, B. W. Roberts and S. Ross (2011). "A gradient of childhood self-control predicts health, wealth, and public safety." Proceedings of the National Academy of Sciences **108**(7): 2693-2698.
Murnane, R., J. B. Willett and F. Levy (1995). "The Growing Importance of Cognitive Skills in Wage Determination." The Review of Economics and Statistics **77**(2): 251-266.
Pandey, S. and D. Van Minh (1998). "A socio-economic analysis of rice production systems in the uplands of northern Vietnam." Agriculture, ecosystems & environment **70**(2-3): 249-258.
Phonvisay, A., B. Vanhnalat and P. Sinavong (2016). Pro-poor Policy Analysis on Cattle Productivity and Industry in Lao PDR. Vientiane, Laos, Food and Agriculture Organization**:** 1-101.
Posner, M. I. and G. J. DiGirolamo (1998). "Executive Attention: Conflict, Target Detection, and Cognitive Control."
Raven, J. (2000). "The Raven's progressive matrices: change and stability over culture and time." Cognitive psychology **41**(1): 1-48.
Raven, J. C. (1936). "Mental tests used in genetic studies: The performance of related individuals on tests mainly educative and mainly reproductive." Unpublished master’s thesis, University of London.
Roca, M., A. Parr, R. Thompson, A. Woolgar, T. Torralva, N. Antoun, F. Manes and J. Duncan (2009). "Executive function and fluid intelligence after frontal lobe lesions." Brain **133**(1): 234-247.
Roder, W., S. Phengchanh and B. Keoboulapha (1995). "Relationships between soil, fallow period, weeds and rice yield in slash-and-burn systems of Laos." Plant and soil **176**(1): 27-36.
Rogers, E. (1995). "Diffusion of innovations." New York **12**.
Roy, A. D. (1951). "Some thoughts on the distribution of earnings." Oxford economic papers **3**(2): 135-146.
Runco, M. A. and S. M. Okuda (1991). "The instructional enhancement of the flexibility and originality scores of divergent thinking tests." Applied Cognitive Psychology **5**(5): 435-441.
Schiller, J. (2006). Rice in Laos, Int. Rice Res. Inst.
Schultz, T. W. (1964). "Transforming traditional agriculture." Transforming traditional agriculture.
Schumpeter, J. A. (1947). "The creative response in economic history." The journal of economic history **7**(2): 149-159.
Stroop, J. R. (1935). "Studies of interference in serial verbal reactions." Journal of experimental psychology **18**(6): 643.
Stür, W., D. Gray and G. Bastin (2002). "Review of the livestock sector in the Lao People’s Democratic Republic."
Tchanturia, K., H. Davies, M. Roberts, A. Harrison, M. Nakazato, U. Schmidt, J. Treasure and R. Morris (2012). "Poor cognitive flexibility in eating disorders: examining the evidence using the Wisconsin Card Sorting Task." PloS one **7**(1): e28331.
Theeuwes, J. (1991). "Exogenous and endogenous control of attention: The effect of visual onsets and offsets." Perception & psychophysics **49**(1): 83-90.
Theeuwes, J. (2010). "Top–down and bottom–up control of visual selection." Acta psychologica **135**(2): 77-99.
Thorell, L. B., S. Lindqvist, S. Bergman Nutley, G. Bohlin and T. Klingberg (2009). "Training and transfer effects of executive functions in preschool children." Developmental science **12**(1): 106-113.
Tintner, G. and O. Brownlee (1944). "Production functions derived from farm records." Journal of Farm Economics **26**(3): 566-571.

Vervloet, M., A. J. Linn, J. C. van Weert, D. H. De Bakker, M. L. Bouvy and L. Van Dijk (2012). "The effectiveness of interventions using electronic reminders to improve adherence to chronic medication: a systematic review of the literature." Journal of the American Medical Informatics Association **19**(5): 696-704.

Appendices

Appendix 1: Descriptions of executive functions

Inhibitory control is the ability to control one's behavior, attention, emotions, or thought. Inhibitory control allows people to choose how to react rather than reacting instinctively to internal predisposition or external temptation (Diamond 2013). Inhibitory control can be disaggregated to two separate parts: interference control and response inhibition. The first part allows us to ignore distracting stimuli that have the potential to distract from one's goal. [9] The second aspect of inhibitory control, response inhibition, does not involve restricting attention to stimuli, but rather restricting behavior or responses. The importance of inhibitory control is shown by Moffitt, Arseneault et al. (2011) who follow 1,000 children from the same city and born in the same year into adulthood to argue that, after controlling for gender, social class, IQ, and the individual family lives of the children growing up, inhibitory control in children has predictive power on outcomes into adulthood: children who displayed more inhibitory control from ages 3 to 11 were more likely as teenagers to stay in school and less likely to use drugs (Moffitt, Arseneault et al. 2011). As adults, children who displayed higher inhibitory control went on to have better mental health, better physical health (e.g. lower body weight, lower blood pressure), higher incomes, lower crime rates, and were found to be happier (Moffitt, Arseneault et al. 2011).

Working memory, which involves holding and manipulating information in mind that isn't currently present (Baddeley & Hitch, 1994; Smith & Jonides, 1999). Working memory differs from short-term memory in that short-term memory only involves holding information without any manipulation of the information (Diamond 2013). The development pattern of working memory is very similar to the abovementioned effect of age on inhibitory control. Children develop the ability to hold information in mind quite early, with infants and young children being able to hold

[9] The first aspect of inhibitory control, interference control, can be further thought of as internal and external inhibition. Internally, unwanted memories and thoughts can be ignored and even forgotten, this is known as cognitive inhibition (Anderson and Levy 2009). Externally, attention can shift suddenly to external stimuli such as a loud noise. This involuntary attention to external stimuli is driven by the properties of the stimuli themselves (Theeuwes 1991). When an individual chooses to ignore these external stimuli and focus on their goals it is most often referred to as selective or focused attention (a.k.a. active attention, attentional control, attentional inhibition, endogenous attention, executive attention, goal-driven attention, top-down attention, volitional attention, or voluntary attention) (Posner and DiGirolamo 1998, Theeuwes 2010).

one or two things in mind for a sustained period (Adele Diamond, 1995; Nelson, Sheffield, Chevalier, Clark, & Espy, 2013). However the ability to hold many things in mind and manipulate information in mind develops much more slowly and comes later in life for individuals after a long developmental process (Cowan, Saults et al. 2002, Luciana, Conklin et al. 2005, Crone, Wendelken et al. 2006, Davidson, Amso et al. 2006, Cowan, AuBuchon et al. 2011). Finally, much like inhibitory control, working memory declines as a natural part of the aging process (Fiore, Borella, Mammarella, & De Beni, 2012; Fournet et al., 2012).

Cognitive flexibility is defined as the ability to adapt to changing circumstances (Friedman, Miyake et al. 2006), involving switching between rules, tasks, or mental sets (Lezak et al., 2004) and allowing an individual to change their view or see things from multiple perspectives.[10] Cognitive flexibility builds on the working memory and inhibitory control develops much later in individuals (Davidson, Amso et al. 2006, Garon, Bryson et al. 2008). Martin and Rubin (1995) and Martin and Anderson (1998) suggest that cognitive flexibility is composed of three steps: individual's awareness that alternatives exist to the current situation, followed by willingness to be adapt to alternatives and, finally, the decision to modify their behavior or switch their beliefs for the current situation.

Fluid intelligence refers to an individual's ability to solve novel problems of which they have no prior experience (Horn and Cattell 1966).[11] It can further be thought of as the ability to solve problems, reason, and to see spatial relationships among items (Ferrer, Shaywitz et al. 2010). Previous studies have found high fluid intelligence, as measured by Raven's progressive matrices (Raven 1936, Raven 2000) to be highly correlated with other independently measured EFs (Kane and Engle 2002, Conway, Kane et al. 2003, Duncan, Parr et al. 2008, Roca, Parr et al. 2009).

Cognitive planning, also known as sequencing, is the ability to create a strategy of steps (in sequence) to achieve intended goals (Dean, Schilbach et al. 2019). To plan well, individuals

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[10] Cognitive flexibility is also referred to as mental flexibility, cognitive shifting, set shifting, or task/attention switching (Canas, Quesada et al. 2003, Tchanturia, Davies et al. 2012).

[11] Together with crystalized intelligence, formed by learned skills, subjects, etc, fluid intelligence form general intelligence

must consider multiple hypothetical steps to reach their desired outcome and then select from the multiple options the one that will most efficiently help them reach their desired goal (Carlin, Bonerba et al. 2000).

Executive functions are largely interdependent, as seen in the figure 3. Working memory relies upon inhibitory control and inhibitory control relies upon working memory. Cognitive flexibility relies upon both working memory and inhibitory control and the higher-level EFs rely upon working memory, inhibitory control, and cognitive flexibility. Interventions focused on any one specific EF will likely have spillover effects into some of the other EFs.

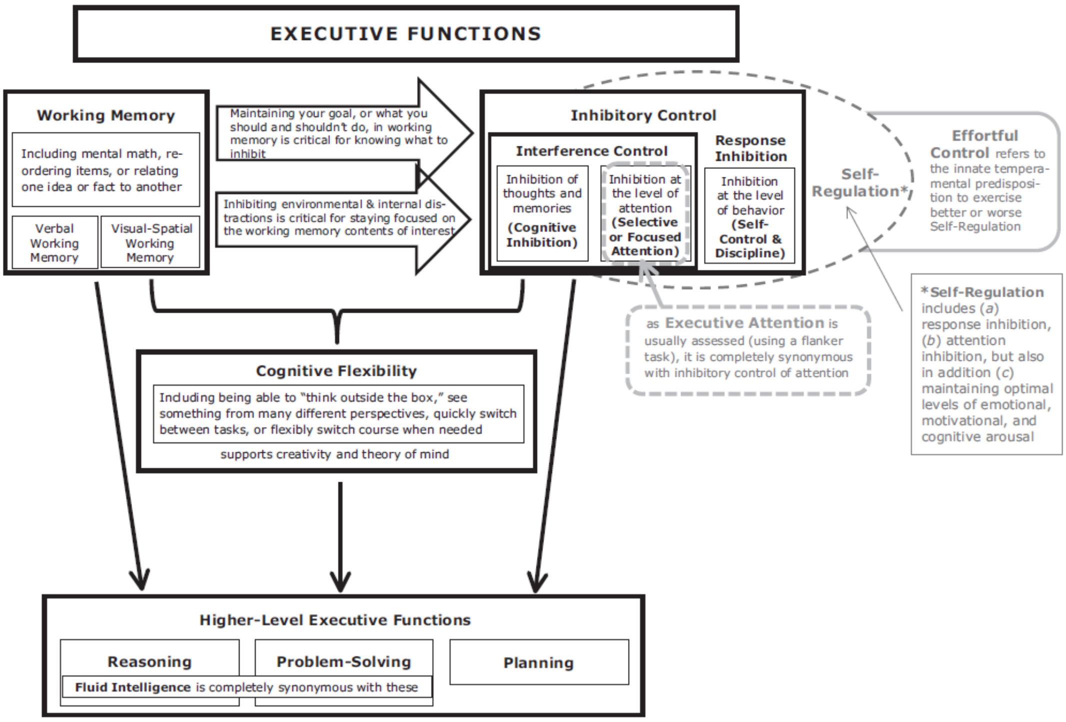

Figure 3. Interrelationship of executive functions (Diamond 2013).

Different EFs are likely to enter an agent's utility function primarily as changes to an agent's preferences as well as their feasible sets. By not acting impulsively and/or being able to focus on the task at hand using inhibitory control, an agent's feasible set should be larger. Inhibitory control allows an agent to be more productive with their time. Inhibitory control will also enter an agent's time preference as it is crucial in delaying gratification and choosing a better option tomorrow over a lesser option today.

Working memory may also change the feasible sets of agents. The ability to mentally store and manipulate information for sustained periods of time can make agents more efficient and productive. An example in agriculture could be an agent performing mental math to determine how much fertilizer to use on a given plot of land. Too little and the crop won't meet its full potential, too much and the excess fertilizer is of no use to the productivity of the plant and is therefore inefficient use of the fertilizer.

Cognitive flexibility is likely to change agent's preferences as well as feasible sets. Cognitive flexibility is important in seeing things from multiple perspectives or changing views. This ability is important when, for example, an agent is considering adopt a new technology. Being able to see themselves in as Dean, Schilbach et al. (2019) say, 'other states of the world' can essentially make it less costly for an agent to make changes because higher levels of cognitive flexibility allow an agent to learn new rules quickly. Higher levels of cognitive flexibility also make task/attention switching easier which could allow agents to engage in multiple and more diverse productive activities. This would allow for different feasible sets as well as different preferences for the agent.

Cognitive planning is a higher-level EF and is likely to change feasible sets for an agent. Agents with higher levels of cognitive planning ability are better at considering multiple hypothetical options that will help them reach a desired goal. This ability to better plan in order to reach a more desirable outcome should loosen constraints and extend an agent's feasible sets.

The final higher-level EF is fluid intelligence. Agents with higher levels of fluid intelligence have a higher ability to solve new problems without any prior experience with them. Similar to cognitive flexibility, this EF can enter an agent's utility function through preferences as it is less costly for agents with higher levels of fluid intelligence to learn new things. This may also translate into more diverse productive activities among the agent, changing their feasible sets.

Appendix 2. Description of executive function measurements

Executive Function	Measurement task	Description	References
Inhibitory control	Numerical Stroop task	Measured using the numerical Stroop task which is the same as the original Stroop task in that individuals are asked to override their automatic responses in favor of more controlled responses. Respondents compare two numbers of different sizes in either congruent pairs (e.g. 6 2) or incongruent pairs (e.g. 6 2) and their response times are measured for either physical or size judgements. Larger inhibition score → lower inhibitory control.	(Stroop 1935) (Besner and Coltheart 1979) (Henik and Tzelgov 1982)
Working memory	Backwards Corsi block test	Measured using the app *Visuospatial Memory Test*. Respondents are required to remember a sequence of numbers in the app and then manipulate the sequence and report it in backwards order from which it was originally presented to measure their working memory. Larger working memory score → higher working memory capacity	(Corsi 1973)
Attention	Psychomotor Vigilance Task	Measured using the Psychomotor Vigilance Task (Mackworth 1948) For these tasks, individuals are asked to respond to a stimulus for an extended period of time. In this specific application, individuals were asked to look at a screen and tap when a dot appears in the top half of a target area but not when it appears in the bottom half. Scores are determined by response time; lower scores equate to better performance.	(Mackworth 1948)
Cognitive flexibility	Berg card sorting task	Individuals are asked to sort playing cards according to different categories such as color, number and shape. They do not know the correct sorting criteria and have to infer the correct criteria through trial and error. The rules for correct sorting automatically change during the game and the individuals once again need to infer the correct criteria. Individuals with higher levels of flexibility are better able to adapt to the new rules and thus have fewer sorting errors. Larger flexibility score → higher cognitive flexibility	(Berg 1948)
Cognitive planning	Tower of Hanoi	Measured by requiring participants to move a series of differently-sized discs from a pole on the left side to another pole on the right side, following a series of rules. The fewer moves it takes an individual to accomplish the task, the higher their ability in cognitive planning. Larger planning score → higher levels of cognitive planning	(Kotovsky, Hayes et al. 1985)
Fluid intelligence	Raven progressive matrices	Measured using a series of progressively harder 3x3 matrix puzzles that have to be solved by correctly selecting the missing piece of each puzzle. This tests the logical reasoning and the individual's ability to solve new problems without any prior knowledge. Larger fluid intelligence score → higher level of fluid intelligence	(Raven 1936) (Raven 2000)

Appendix 3. Probit selection model for rice production by year

	2017		2018	
Variables	Mean	St. Error	Mean	St. Error
Cognitive planning	-0.000	(0.051)	-0.015	(0.049)
Fluid intelligence	-0.068	(0.077)	-0.019	(0.071)
Inhibitory control	0.235	(0.610)	-0.026	(0.603)
Working memory	0.051	(0.075)	-0.031	(0.074)
Cognitive flexibility	-0.079	(0.074)	0.053	(0.067)
Attention	0.020	(0.077)	0.039	(0.073)
Risk preference	-0.010	(0.028)	0.035	(0.027)
Time preference	-0.399	(0.513)	-0.459	(0.452)
Schooling	-0.038	(0.031)	-0.062**	(0.029)
Age	-0.016**	(0.006)	-0.009	(0.006)
Male	0.677**	(0.325)	0.156	(0.283)
Literacy	-0.737**	(0.374)	-0.301	(0.321)
Male labor (13-17)	0.031	(0.140)	-0.067	(0.112)
Female labor (13-17)	0.092	(0.139)	-0.022	(0.113)
Male labor (18-60)	0.259***	(0.088)	0.192**	(0.082)
Female labor (18-60)	0.077	(0.106)	-0.076	(0.084)
Dependency Ratio	0.187*	(0.101)	0.073	(0.102)
LFA policy	-0.225	(0.249)	-0.232	(0.230)
Distance to market (km)	0.015*	(0.009)	0.015*	(0.008)
Communal grazing (ha)	-0.000	(0.000)	-0.000***	(0.000)
Communal forest (ha)	0.000	(0.000)	0.000	(0.000)
Village irrigation scheme	0.209	(0.208)	0.505**	(0.207)
Number of extension visits	-0.002	(0.018)	-0.048***	(0.018)
Rainy season car access	-0.503**	(0.198)	-0.458***	(0.176)
Mixed ecosystem	-0.976***	(0.301)	-0.702***	(0.230)
Upland ecosystem	-1.201***	(0.314)	-0.632***	(0.232)
Distance to District HQ (km)	0.007	(0.005)	0.016***	(0.005)
Constant	2.96***	(0.764)	2.74***	(0.620)
Observations	714		711	

Note: '***', '**', and '*' are significant at 1%, 5%, and 10% respectively

Appendix 4. Heckman Selection and Tobit model for rice production by year

	Heckman				Tobit			
	2017		2018		2017		2018	
Variables	Mean	St. Error	Mean	St. Error	Mean	St. Error	Mean	St. Error
Cognitive planning	-6.4	(93.0)	1.4	(89.1)	5.0	(50.7)	-42.4	(45.1)
Fluid intelligence	-49.9	(147.7)	61.1	(134.5)	-143.3*	(82.2)	42.1	(76.6)
Inhibitory control	146.739	(1,230.7)	71.4	(1,176.1)	499.8	(699.1)	77.6	(632.9)
Working memory	-45.717	(149.5)	-1.2	(146.9)	-18.5	(91.2)	-77.4	(74.2)
Cognitive flexibility	200.4	(152.4)	40.4	(145.8)	90.5	(81.7)	50.8	(76.0)
Attention	-58.8	(135.8)	1.4	(133.1)	-49.4	(68.9)	39.8	(68.8)
Risk preference	38.7	(52.8)	-20.0	(53.8)	31.2	(34.2)	24.3	(26.8)
Time preference	617.2	(1,001.2)	1,627.7*	(980.1)	355.6	(608.0)	1,210.7**	(540.4)
Schooling	19.7	(59.8)	65.7	(67.7)	-40.9	(34.2)	-38.8	(34.2)
Age	8.4	(14.4)	13.0	(12.6)	-14.8**	(6.8)	-4.9	(5.9)
Male	558.9	(849.6)	370.9	(713.5)	1,375.2***	(355.3)	625.0**	(313.3)
Literacy	770.1	(570.6)	272.2	(501.9)	217.8	(257.9)	137.6	(252.5)
Farm size (ha)	41.9	(46.7)	64.7	(43.2)	29.5	(34.5)	39.3	(29.9)
Forest (ha)	20.9	(71.0)	116.2*	(68.7)	35.4	(46.1)	88.9*	(50.5)
Ag asset index	756.6***	(181.8)	589.1***	(169.2)	960.7***	(128.0)	771.4***	(116.3)
Male labor (13-17)	43.6	(225.8)	163.4	(222.1)	82.4	(141.5)	76.2	(117.7)
Female labor (13-17)	-28.5	(203.7)	3.7	(197.0)	10.1	(104.2)	-49.1	(96.8)
Male labor (18-60)	90.0	(214.0)	30.9	(197.0)	351.2***	(97.4)	242.5***	(89.7)
Female labor (18-60)	89.5	(172.7)	117.4	(168.0)	173.4	(118.3)	25.7	(90.3)
Dependency Ratio	115.6	(236.7)	-37.9	(212.6)	343.0***	(131.5)	91.9	(107.2)
Pakxieng district	-475.0	(532.5)	-1,132.0**	(514.9)	-628.2**	(319.0)	-1,824.5***	(294.8)
Viengkham district	-176.0	(503.2)	-795.2*	(474.1)	-295.7	(324.9)	-1,072.4***	(292.5)
Phoukhout district	-436.2	(488.0)	-845.9*	(452.6)	-361.2	(308.1)	-833.2***	(266.5)
Number of ext. visits	6.3	(42.1)	75.9	(51.3)	1.8	(22.0)	4.0	(21.5)
Rainy season car access	476.9	(475.4)	433.5	(482.8)	-165.5	(207.1)	-336.9*	(184.0)
LFA policy	612.8	(409.5)	649.1*	(393.9)	352.4	(227.0)	435.3*	(221.9)
Distance to market (km)	-25.5	(16.8)	-16.9	(16.7)	-7.3	(7.9)	-1.8	(7.5)
Communal grazing (ha)	0.17	(0.24)	0.23	(0.284)	-0.12	(0.12)	-0.38**	(0.11)
Communal forest (ha)	-0.10	(0.07)	-0.09	(0.070)	-0.07**	(0.03)	-0.02	(0.03)
Village irrigation scheme	-232.0	(401.1)	-577.8	(456.9)	-198.4	(249.2)	-197.6	(218.4)
Distance to District HQ (km)	-11.7	(10.3)	-24.0**	(12.0)	-0.25	(5.1)	-7.2*	(4.3)
Mixed ecosystem	1,134.7*	(587.8)	840.8	(582.4)	301.0	(265.1)	109.9	(259.6)
Upland ecosystem	1,020.5	(745.5)	563.8	(625.4)	57.1	(313.1)	196.1	(304.4)
lambda	-3,425.9	(2,478.6)	-3,253.8	(2,453.0)				
Constant	462.0	(1,180.5)	848.9	(1,160.0)	1,101.9*	(656.9)	2,066.3***	(528.9)
Observations	714		711		714		711	

Note: '***', '**', and '*' are significant at 1%, 5%, and 10% respectively