Poverty and Cognitive Function*

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1 Introduction

Economic growth has lifted billions out of poverty in a span of a few generations. Simultaneously, measurement of the financial interactions of the poor has improved dramatically, generating a wealth of insights into their financial lives. Despite these positive trends and many poverty alleviation efforts, poverty still remains entrenched for millions around the globe. One long-standing explanation for poverty's persistence is the possibility of poverty traps, or self-reinforcing cycles of poverty.

Theoretical models of such poverty traps, often centered on nutrition in the earliest cases, have been central in development literature for over half a century (Leibenstein, 1957; Mirrlees, 1975; Stiglitz, 1976; Bliss and Stern, 1978; Dasgupta and Ray, 1986). This literature has expanded in many directions to consider the varying potential underlying forces such as geographic characteristics, pecuniary externalities, and even cultural forces, as well as both theoretical and policy implications of such traps ranging from inter-generational transmission of poverty to equilibrium unemployment (Jalan and Ravallion, 2002; Sachs, 2005; Fang and Loury, 2005; Currie and Almond, 2011; Barrett and Carter, 2013; Sachs, 2014; Kraay and Raddatz, 2007).

Despite the burgeoning literature in this area and the policy appeal of potentially instigating virtuous and self-reinforcing cycles of income growth and wealth, the empirical evidence that such traps exist remains mixed (Banerjee and Duflo, 2011; Kraay and McKenzie, 2014; Barrett et al., 2016). Moreover, even in the instances where actual evidence is consistent with such traps, their exact mechanisms remain unclear (See Banerjee et al. (2015); Bandiera et al. (2015)). One potential underlying mechanism that has yet to be explored in depth is cognition.

On the path from initial wealth to cognition, poverty may affect cognitive function in a variety of ways. Evidence is beginning to accumulate that cognitive functions are limited resources which can be strained by living in poverty (Schilbach, Schofield and Mullainathan, 2016). Being forced to make constant trade-offs with limited resources can act as a "load" on cognition (Mullainathan and Shafir, 2013). In addition to capturing individuals' minds, poverty often entails a number of material deprivations which may further impede cognition. Many correlates of poverty, such as poor sleep, chronic pain, malnutrition, and high alcohol consumption, have been shown to tax cognitive resources (Lim and Dinges, 2010; Moriarty et al., 2011; Schofield, 2014; Schilbach, 2015). Following the path the other direciton, the resulting reductions in these cognitive resources may have broad feedback effects on earnings and wealth, ranging from occupational choice to technology adoption, consumption patterns, and risk and time preferences. In other words, the relationship between cognitive function and poverty could be bi-directional, generating the potential for feedback loops, reduced mobility and—if the resulting effects are large enough—poverty traps.

Despite the potential importance of cognitive function in the lives of the poor, there are likely to be many challenges in establishing cognition's role in forming a poverty trap. First among these is that both the factors impeding cognition and the downstream effects of reduced cognitive function are likely to be diffuse, making measurement of feedback effects challenging. Although the breadth of the potential effects creates a challenge, it also highlights the potential for wide-reaching consequences. Further, beyond a potential role in creating feedback loops which increase the persistence of poverty, an enhanced understanding of the psychological or cognitive lives of the poor is, in and of itself, of substantial value. Improved understanding of the financial lives of the poor over the previous few decades have generated a wealth of insights; for example, the wealth of data from financial diaries has shed light on the incredible complexity of the financial lives of the poor – with those in poverty often balancing a dizzying array of transactions, income streams, and debts. This data has lead to both improved theory and to improved policy. With cognition's potential to shape virtually every aspect of life, including not just labor market outcomes, but also decision-making and even utility and welfare, improving our understanding of the psychological lives of the poor has similar potential in both domains.

The goal of this paper is to highlight the potential interplay between cognitive function and poverty and, in doing so, to facilitate further study of this potential bi-directional mechanism by providing a "primer for economists" on areas of cognitive function, their measurement, and their potential implications for poverty. The remainder of this paper is as follows. Section 2 provides a concise overview of cognitive functions for economists, including definitions and descriptions of four key areas. Moreover, this section discusses how to measure the different aspects of cognition in order to quantify potential effects of poverty and to facilitate further research in this area. Section 3 then summarizes the existing evidence of the potential impact of poverty on cognitive function via various channels, including malnutrition, alcohol consumption, monetary concerns, physical pain, sleep deprivation, and other environmental factors. Section 4 shifts focus to the impact of different areas of cognitive function on economic outcomes, and more broadly to future income, wealth, decision-making, and poverty. Finally, Section 5 concludes by highlighting open questions and high-value areas of future research in the relationships between cognitive function and poverty.

2 Cognitive Functions

This section provides a brief overview of cognitive functions, intended as a "primer for economists." Following this overview, we will discuss four key aspects of cognitive function in detail as well as canonical tests to measure them. Additional detail on the cognitive functions we consider here can be found in Lyon and Krasnegor (1996), Suchy (2009), and Diamond (2013).

2.1 Overview of Cognitive Functions

The brain and its many functions have been studied by researchers in psychology, neuroscience, and other fields for many decades. Each of its roles—e.g. movement, sensory input, and interpretation—are essential to daily life. There is, however, one set of functional areas that is of particular relevance and interest to decision-making and economic life. Termed cognitive functions in the cognitive psychology literature, these processes are broadly defined as mental processes that control one's attention, dictate one's ability to work with information, and are required for deliberate activity. Cognitive functions are crucial to task performance and decision making, and carry longer-term impacts such as literacy and school performance (Borella et al., 2010; Duncan et al., 2007).

Cognitive functions are top-down processes, initiated from the pre-frontal cortex of the brain, that are required for deliberate thought processes such as forming goals, planning ahead, carrying out a goal-directed plan, and performing effectively (Lezak, 1983; Miller and Cohen, 2001). Although most researchers agree on this general understanding of cognitive functions, there is a wide array of views on details ranging from how to categorize its sub-components to which neurological brain circuits are required for different areas of functioning (Jurado and Rosselli, 2007). For example, a topic of debate is whether there exists one unifying mechanism underlying all cognitive functions, also known as the "Theory of Unity" (Kimberg et al., 1997; de Frias et al., 2006; Godefroy et al., 1999).

While beliefs are wide-ranging, the views of most researchers fall in the middle of this spectrum, taking the position that while there is no one unifying mechanism, broad classification of sub-components is possible (Miyake et al., 2000). In this paper, we will utilize this middle-ground approach and focus on aspects of cognitive functions that are both generally agreed upon by cognitive psychologists and that we consider central to understanding economic behavior and outcomes. With this overview is mind, we will focus on four generally agreed-upon areas of cognitive function:

(I) **Attention** is the ability to focus on particular pieces of information by engaging in a selection process that allows for further processing of incoming stimuli which can happen voluntarily or involuntarily. For instance, attention alerts us to sudden loud noises (involuntarily) or enables us to comprehend a bullet point on a presentation slide (voluntarily).

(II) **Inhibitory Control** is the ability to control impulses and minimize interference from irrelevant stimuli. It is used to block out distractions, to control impulsive urges, and to override pre-potent responses (Rothbart and Posner, 1985). For example, an application of inhibitory control is stopping yourself from reaching for a chocolate cookie on the table when you are exhausted after a long day.

(III) **Memory** is the ability to recall, recognize, and utilize previously learned information. Of particular interest in this paper is working memory, the ability to evaluate new information as it enters, to manipulate the information if necessary, and to delete or update irrelevant existing information. For example, the use of working memory enables us to remember a conversation with another conference attendee, and then to revisit the topic later and update a draft paper.

(IV) **Higher-Order Cognitive Functions** involve one or more of the basic cognitive functions highlighted above and are therefore perceived as more complex. This paper will discuss two higher-order cognitive functions: cognitive flexibility and intelligence.

Cognitive flexibility is a higher-order ability that involves switching between tasks, rules, or mental sets (Lezak et al., 2004). For example, if a small business owner decides to implement a new bookkeeping system, adjusting to this change requires a combination of inhibiting existing habits, attending to the old and new rules, and actively adopting the new system—a more involved process compared to one that merely relies on a single cognitive function. Cognitive flexibility is also used interpersonally, helping us to understand others' perspectives in situations of potential interpersonal conflict.

Intelligence is commonly separated into fluid and crystallized intelligence. The former refers to the ability to solve novel problems, and the latter involves the abililty to use learned languages, subjects, skills, and so forth. Both forms of intelligence involve a combination of core functions such as attention and memory, rendering them "higher-order," i.e. more complex cognitive functions (Cattell and Horn, 1966).

Each of these broad constructs has the potential to help shape our understanding of the relationship between poverty, decision making, and productivity. Each has direct relevance to a variety of types of economic decision making, as well as the potential to be shaped by poverty, or correlates of poverty such as chronic pain, leading to feedback effects of poverty. Such effects may in turn lead to reduced socioeconomic mobility or potentially even poverty traps. Before discussing the potential relationship between these areas of cognitive function and economic outcomes, we provide a more thorough description of each area of cognition, as well as examples of ways to measure them, in order to facilitate their integration into economic studies. Appendix Table A.1 provides a summary of these tasks used to measure cognitive function, including some of their advantages and disadvantages for use in development economics.

2.2 Attention

2.2.1 Definition and Description of Attention

Given its fundamental nature underlying several other cognitive functions and its relevance to decision making, attention has garnered exceptional interest among both cognitive psychologists and economists (Pashler, 1998). This interest has generated a wide-ranging and deep literature in cognitive psychology, with many active debates and disagreements about the precise definition, role, and boundaries of attention. This paper aims to define attention in a manner consistent with the prevailing views in cognitive psychology, while noting some of the most substantial disagreements with that view. We focus on *conscious* attention for the purposes of this paper, as opposed to aspects of attention, such as priming, that could happen subconsciously.

At its most basic level, attention is the selection of information for further processing. That is, attention filters information into or out of processing mechanisms. People are faced with millions of stimuli every day. Our brains filter out a large majority of them, enabling us to focus more effectively on the things we care about (Sternberg and Sternberg, 2011; Treisman and Gelade, 1980; Cohen, 2014). Given this filtering role and because one usually attends to a stimulus before being able to retain or recall information, the early and still prevailing view is that attention is a key component of memory (Yates, 1966; Phelps, 2006).

Within the realm of attention, researchers have made significant headway in understanding the mechanisms underlying attention by separating it into categorical types:

Internal vs. external attention. One such categorical distinction is the separation between internal and external attention (Chun et al., 2011). Internal attention is the selection, modulation, and maintenance of internally-generated information. For instance, thinking about the upcoming deadline for a journal submission. In contrast, external attention is the selection and modulation of incoming stimuli from your surroundings, e.g. viewing images as they appear on a television screen.

Simple vs. complex attention. Another classification draws a distinction between simple and complex attention, as proposed by Lim and Dinges (2010). Simple attention refers to attending to one stimulus, whereas complex attention refers to attending to multiple stimuli at the same time. While this categorization is not very common among psychologists, measurement tasks devised to measure cognitive functions can be to a large extent related to either simple or complex attention. As such, this categorization provides a straightforward structure to understand attention and, in particular, to study the potential relationship between poverty and cognitive function.

Other classifications. Other classifications are arguably less informative when considering downstream effects such as economic decision making and productivity. For example, posterior and anterior attention studied in neuroscience focus on the specific neurotransmitters that are active in the brain when attending to different stimuli and investigate in depth the particular brain cells at play (Peterson and Posner, 2012). Due to our focus on the relationship between cognition and economic outcomes of interest, these discoveries are not our primary focus; therefore we proceed with the simple versus complex attention categorization. The next section provides examples of tests measuring simple and complex attention.

2.2.2 Measuring Attention

One of the areas of attention with potentially serious consequences to human behavior is 'sustained attention', also commonly referred to as "vigilance" or "attentional vigilance" (Egeland et al., 2009). This skill is the general ability to detect a stimulus during times of habituation and/or tiredness (Mackworth, 1968; Robertson et al., 1997). In lab and field settings, measuring vigilance usually involves of identifying a target signal from a pool of otherwise continuous and repetitive non-target stimuli. This section describes canonical tasks used to measure this skill, in both its simple and complex forms.

I. Psychomotor Vigilance Task. Within simple attention, one widely used and respected task to measure attentional vigilance is the Psychomotor Vigilance Task (PVT). The PVT is especially popular among sleep researchers (Basner and Dinges, 2011; Basner et al., 2011; Dinges et al., 1997). In this task, researchers ask participants to press a button when a stimulus appears, for instance, a light or a colored dot. The task measures reaction time and accuracy—in other words, how quickly the participant (correctly) presses the button when the stimulus appears, and how often she presses the button when no stimulus appears (a false response). In a review by Basner and Dinges (2011), the most common outcome metric of the PVT is the number of lapses, reported by 66.7% of published studies. Lapses are usually defined as a reaction time of longer than 500 milliseconds and are understood as breaks in one's attention (Lim and Dinges, 2008). Other commonly used metrics are mean reaction time, inverse reaction time, fastest 10% of reaction times, and median reaction time. The PVT collects extremely granular data, as it is administered on a computer (or other electronic device) and records time on a millisecond scale. Researchers can easily adjust factors such as inter-stimulus interval – the time between the appearance of two stimuli. The task does not show learning effects and is not affected by aptitude differences, making it ideal for repeated use in within-subject designs (Dorrian et al., 2005). The task does, however, require electronic administration, which can make it inconvenient in certain field settings. Increasing the duration of the task generally increases error rates, especially when implemented along with a battery of other cognitive tasks (Lim et al., 2010).

II. Concentration Endurance Test. In contrast to simple attention tasks, complex attention tasks involve more than one stimulus and/or more than one rule. The *Concentration Endurance Test*, also known as the "d2 Test of Attention," is a task that aims to measure sustained attention (Bates and Lemay, 2004). Participants view a continuous list of letters *p* and *d*, with up to two marks above and up to two marks below each of the letters. The participants then identify and cross out only the letters *d* that have two associated marks. Common outcome variables include the total number of correct cancellations, errors, and the distribution of errors. The task requires participants to recognize the letter "d", making literate participants more easily able to complete the task, but it can be administered using similar shapes as opposed to letters for non-literate participants or participants whose native language does not use the Latin alphabet. Notably, the task requires accurate visual scanning, which can be impeded not only by poor attention, but also by poor eyesight, a common concern in developing countries.

2.3 Inhibitory Control

2.3.1 Definition and Description of Inhibitory Control

Inhibitory control is a top-down mental process that blocks out distractions, controls impulsive urges, and overrides pre-potent responses (Rothbart and Posner, 1985). It is sometimes used interchangeably with self-control, and is also referred to as "selective attention," "attentional control," "attentional inhibition," and "executive attention" (Lavie et al., 2004; Kane and Engle, 2002; Kaplan and Berman, 2010). The ability to control impulses has been thoroughly studied in child development (Carlson and Moses, 2001; Diamond and Taylor, 1996; Mischel et al., 1989) and among adults (Ward and Mann, 2000; Dempster, 1992). This important aspect of cognitive functioning enables people to perform well socially, physically, at work, and in society. For example, discipline and self-control are required to refrain from eating when on a diet (Shiv and Fedorikhin, 1999), or to inhibit socially inappropriate responses when mentally drained (von Hippel and Gonsalkorale, 2005).

One notable model of self-control proposes that self-control is goverened by a limited resource that can be depleted over time (Baumeister et al., 1998; Muraven et al., 1998). This model, known as the "ego-depletion" model, has been empirically tested, with meta-analyses finding small effect sizes (Hagger et al., 2015).

However, situational factors can have a significant effect on self-control. In addition to individual differences, variable factors in one's environment or life circumstances such as fatigue or cognitive load could also affect the availability of this limited mental resource (Inzlicht and Schmeichel, 2012; Muraven and Baumeister, 2000). For example, it is much more difficult to suppress one's impulses after exposure to stress (Glass et al., 1969) or when working in a crowded space (Sherrod, 1974), both prevalent conditions faced by the urban poor. Empirically, recent prominent work on self-control has focused on exploring the consequences of depleted self-control and ways to overcome this depletion (Baumeister, 2002; Hofmann et al., 2007, 2009).

2.3.2 Measuring Inhibitory Control

The following section describes a subset of the many cognitive tasks researchers use to measure inhibitory control. Researchers have applied the tests discussed below in a wide range of settings and populations, providing a useful guide for designing future experimental studies related to inhibitory control.

I. Hearts and Flowers Task. This task, previously known as the *Dots Task*, shows participants a screen which is divided into two panels where either a heart or a flower appears on one side of the screen. In a first round, participants are shown only hearts and are asked to click a button on the same side as the heart whenever it appears. In the second round, only flowers appear and participants are asked to click on the opposite side of the screen as the flower. Finally, in the third round, individuals are see both hearts and flowers, and the goal is to click on the appropriate side of the screen according to the stimulus and the rule. Rounds two and three measure inhibitory control, as they require individuals to override their natural tendency to press on the same side whenever flowers appear on the screen. A different version of this test, using arrows instead of symbols, is particularly effective at separating inhibitory control from other cognitive functions (Davidson et al., 2006).[1] The test can be made more difficult by decreasing the amount of time individual stimuli appear, or by increasing the threshold for correct answers. Though this task is most effective administered electronically, it is well-suited for economic development research. It is quick, easy to explain, and does not require specific background knowledge or education level, making it applicable in a wide range of settings.

II. Eriksen Flanker Task. In this task, participants are shown a set of five stimuli, of which they are supposed to respond only to the middle stimulus (Eriksen and Eriksen, 1974; Mullane et al., 2009). A common version of this task uses an arrow as the target (middle) stimulus. Respondents have two buttons – one left and one right – and are asked to press the button coresponding to the direction of the target arrow. The target stimulus can be flanked by congruent stimuli (e.g. arrows pointing in the same direction as the target), incongruent stimuli (e.g. arrows pointing in the opposite direction of the target) or neutral stimuli (e.g. squares flanking the target arrow). Incongruent stimuli require participants to use top-down control to focus on the middle stimulus

[1] As it only requires participants to hold one rule in mind at a time it does not require working memory.

(Diamond, 2013). When the task uses an arrow it minimizes memory requirements from participants, as the arrows indicate where the participant is supposed to respond. This task is best performed electronically, and researchers have limited ability to manipulate its difficulty. When conducted using arrows as described above, however, the test does not require any background knowledge or educational attainment level, and effectively separates inhibitory control from other cognitive functions such as working memory.

III. Stroop Test. While there are a number of versions of the *Stroop test*, in this paper, we will detail two: the *Classic Stroop test* and the *Spatial Stroop test*.

The *Classic Stroop Test* displays a list of words that spell out the names of colors (Stroop, 1935). The congruent condition occurs when the word matches the color of ink (e.g. the word "blue" is displayed in blue ink). Conversely, the incongruent condition occurs when the word is displayed in a different color ink (e.g. the word "blue" displayed in green ink). The goal of the task is to name the color of the ink as opposed to the word, for instance, blue in the congruent condition and green in the incongruent condition (MacLeod, 1991).[2] Although it is a common test in developed countries, the Stroop test has several disadvantages for development researchers. First among these is that most versions require literacy, and different educational levels are likely to affect performances. A numeric version of the task can overcome the literacy barrier, although it may still be problematic if numeracy is also low. The test is also typically conducted electronically (though it can be done with paper and a stopwatch) and there is little researchers can do to manipulate its difficulty other than shorten the response time.

The *Spatial Stroop test* relies on the same basic concept as the classic Stroop Test but measures spatial rather than verbal and visual incompatibility. Researchers show participants both relevant and irrelevant dimensions of a stimulus, which are similar and can influence responses. For example, in one variant, participants are shown an arrow which points left or right (in another variant they are shown the words "LEFT" or "RIGHT") and is displayed on either the left or right side of the computer screen. Participants are asked to press the button on the side the arrow is pointing to, ignoring the location of the arrow on the computer screen. While the side of the screen on which the stimuli appear is irrelevant, respondents tend to be quicker when the stimuli appear on the same side as their associated response (Lu and Proctor, 1995). This version of the task has an advantage over the classic Stroop Task in that it does not require literacy when using the arrow stimuli. Though generally administered electronically, this task is otherwise well-suited to field

[2]Although the classic Stroop test is a prototypical test of inhibitory control (Miyake et al., 2000), MacLeod et al. (2003) notes that the classic Stroop test, might not, in fact, measure inhibition. The authors note that the "Stroop effect"—delayed response when ink color differs from that of the displayed word—is the same when using dictionary words and when using pronounceable but non-dictionary words which have no representation, and therefore no inhibition should occur in the latter set of words.

settings, as it is both quick and easy to explain. Researchers can also alter the difficulty of the task easily by adjusting its speed.

2.4 Memory

2.4.1 Definition and Overview of Memory

Memory is the ability to encode, store, retain and retrieve information and previous experiences (Kandel et al., 2000). This ability to retain and use previous knowledge supports relationship building and is essential to learning. Memory has multiple components; for instance, auditory memory is the ability to process oral information (information given "out-loud"), whereas visual memory is the ability to remember what one has seen. Memory can be short-term, when information is only retained in the brain for a short amount of time, or can be stored for long-term usage via rehearsal or active processing. Closely connected to short-term memory is working memory, in which information is both stored and manipulated in the brain. More information on short-term, long-term, and working memory follows.

Short-Term Memory and Long-Term Memory. Research on memory has explored the relationship and interactions between what we commonly and intuitively refer to as "short-term memory" and "long-term memory" (James, 1890). Short-term memory is defined as information that enters into conscious memory through a sensory registry such as through the eyes or sense of touch. Information then resides for a short period of time in the conscious memory but will be forgotten if not deliberately rehearsed or managed. Scientists generally agree that the capacity of short-term memory is limited, as with, 7 plus or minus 2 considered to be the typical number of items one can hold in short-term memory at the same time (Miller, 1956). Following extensive rehearsal and active processing, information solidifies and moves into long-term memory, where it is retained for future use. When people's actions, decisions, and speech require them to retrieve information from long-term memory, the memory or information moves back into short-term memory for active use. Compared with the limited capacity in the short-term store, researchers hypothesize that the capacity of the long-term store is unlimited (Cowan, 2008).

Working Memory. Research in recent decades has largely replaced the concept of short-term memory with an integrated, multi-component classification known as working memory (Baddeley and Hitch, 1974). Working memory refers to the set of cognitive processes involved in the temporary storage *and* manipulation of information (Diamond, 2013). For example, a waitress taking orders at a dining table could use working memory to remember all the orders without writing anything down. She might also manipulate the "data" in her mind by grouping all the appetizers together, all the drink orders together, and so on. This combination of temporary storage and manipulation is the core of working memory. As with short-term memory capacity, individuals' working memory capacity is limited. There is some disagreement among researchers in psychology on how working memory fits into the broader category of cognitive function. In particular, there is a blurred line of separation between working memory and inhibitory control. One possibility is to group inhibitory control with working memory (Hasher and Zacks, 1998, 2006), which is popular within computational modeling (Miller and Cohen, 2001; Munakata et al., 2011). However, here we treat working memory and inhibitory control separately due to their differential impacts on economic outcomes, as we will outline in Section 4.

2.4.2 Measuring Memory

Cognitive psychologists have devised numerous cognitive tasks that capture short-term and working memory. Below, we discuss three such tasks, including their relevant variations.

I. Digit Span Tasks. To measure short-term memory, researchers often use the *Forward Digit Span Task* in which participants are read a list of numbers then ask participants to repeat these numbers in the same order (Daneman and Carpenter, 1980, 1983). Participants with a lower level of numeracy may be at a disadvantage in this task, so researchers can substitute simple items or words in place of numbers as needed. One also can modify this task to have participants listen to and repeat non-numerical items and reorganize them. For instance, modifications might include providing participants with a series of letters to list back in alphabetical order (requires literacy) or a series of objects to list back in order of size (requires background knowledge of items, which may differ across settings). This task is easy to implement in the field—it does not require any equipment other than what is needed to record participants' responses. Outcomes for this study are accuracy and number of digits/items, thus it is easy to make this test more challenging by increasing the number of digits or objects the participants are asked to remember. A close cousin to the Forward Digit Span Task, the *Reverse Digit Span Task*, asks participants to listen to a list of numbers and repeat them in reverse, numerical, or reverse-numerical order. This version of the task is commonly used as a measure of working memory because it requires some manipulation of information instead of mere repetition. This task entails the same implementation issues as the Forward Digit Span Task, but similar modifications can be implemented.

II. Corsi Block Test. The Corsi Block Test (Corsi, 1972) is well suited to measure visual-spatial memory (Lezak, 1983). Participants view a series of spatially-separated blocks which individually change colors in a random sequence. They then tap or click the series of blocks in the order in which they changed color. In an alternative version of this task, a researcher will tap individual blocks and participants are then asked to tap these blocks in the same order as the researcher. The sequence typically starts out with a small number of blocks then becomes more difficult as the number of blocks in the series increases. As initially designed, the *Corsi Block Test* does not require mental manipulation, which categorizes it as a short-term memory test rather than a working-memory test. However, there is a version of the test with a working-memory component, as it requires participants to reorder the indicated blocks (Feng et al., 2007). Likewise, the reverse Corsi block test, where participants reverse the order of the indicated blocks, measures working memory. The Corsi Block Test is also relatively easy to implement in the field; it can be administered on paper or electronically, and a tablet version, eCorsi, has been developed (Brunetti et al., 2014). The task also does not require any particular background (such as numeracy) making it particularly well-suited for development research. Furthermore, researchers can be easily increase the test's difficulty by increasing the number of blocks respondents must remember.

III. Self-Ordered Pointing Task. This test measures non-spatial or spatial working memory (Petrides et al., 1993; Petrides and Milner, 1982). In this task, participants are shown three to twelve objects (in the form of boxes with line drawings or other identifiable stimuli), and are then asked to touch one item at a time, without repeating items, until each object has been touched. However, the test randomly scrambles the locations of the objects in between turns. A modification of this task which measures spatial working memory has identical objects that remain stationary throughout the task (Diamond et al., 2007; Wiebe et al., 2010). One can to manipulate the difficulty of this task by increasing the number of items. The task can be carried out either electronically or using physical objects (or paper drawings). Further, this task does not require participants to have a specific background or a certain level of education, making it appropriate in a wide range of settings.

2.5 Higher-Order Cognitive Functions

2.5.1 Definition and Description of Higher-Order Cognitive Functions

In the previous sections we present attention, inhibitory control, and memory as uni-dimensional cognitive functions because researchers attempting to understand the human mind typically focus on one specific aspect of functioning while controlling for or mitigating the influence of unrelated areas in order to obtain the cleanest results. As described previously, however, attention, inhibitory control, and memory are all interrelated and difficult to fully disentangle, because they utilize the same region in the brain (Stuss and Alexander, 2000)[3].

In fact, the human behavior we observe in real life rarely relies on one cognitive domain alone

[3]Diamond (2013) Figure 4 is an excellent summary of the interrelation of cognitive functions

and instead more often than not, requires a combination of these underlying functions. For example, think about the seemingly simple act of crossing a road, an "activity" most of us do every day. All of the core cognitive functions are at play here. First, you pay attention to the traffic light and the passing vehicles on the road. Looking at the cars, you begin to calculate, using working memory, the speed and distance of the car and contemplate the possibility of whether jaywalking seems safe enough. However, you decide to suppress your impulse to jaywalk because the young child next to you is patiently waiting for the green light and you want to set a good example; you exert inhibitory control. This example illustrates the complexity involved in almost every decision or action we take. Instead of using a uni-dimensional cognitive function, our actions and decisions typically require a multi-dimensional approach, combining several of the cognitive functions discussed so far. In this section, we discuss the more advanced types of cognitive functions, which we refer to as "higher-order cognitive functions," focusing on cognitive flexibility and intelligence, two key areas with the potential to greatly impact economic outcomes.

Cognitive Flexibility. The ability to adapt to changing circumstances is referred to as cognitive flexibility (Friedman et al., 2006; Andrewes, 2001). This mental process is used when a situation is altered and there is a need to adapt to it by updating the old rules to reflect the new circumstances, rules, or environment. Cognitive pyschologists hypothesize that cognitive flexibility is composed of three steps (Martin and Rubin, 1995; Martin and Anderson, 1998). The first is an awareness that there are options and alternatives available in a given situation. The second is a willingness to be flexible and adapt to a given situation. The third is the decision to make the switch and modify behavior or beliefs given the situation. Researchers argue that all three steps are critical because you cannot adapt to a new rule without an awareness of it, and similarly, you would not successfully adapt to the new rule without the willingness and ability to change.

Cognitive flexibility is also referred to as set shifting, task switching/shifting, attention switching/shifting, cognitive shifting, and mental flexibility (Tchanturia et al., 2012; Canas et al., 2002). Implicit in all these various is the element of change and the ability to update previous beliefs and/or actions in response to changes in the environment (Monsell, 2003).

Fluid and Crystallized Intelligence. General intelligence is is typically considered to have two components: fluid intelligence and crystallized intelligence (Horn and Cattell, 1967). *Fluid intelligence* refers to the ability to solve novel problems and to adapt to new situations. Frequently represented by the variable gF in the literature, researchers believe fluid intelligence exists independently of acquired skills and knowledge (Cattell, 1963). Individuals who use logic such as deductive reasoning to solve a puzzle or think about problems abstractly employ fluid intelligence. As a higher-order cognitive function, it is most often associated with memory, in particular, working memory, which involves updating and manipulating information (as described in section 2.4). In contrast, *crystallized intelligence*, commonly abbreviated as *gC*, relies on acquired skills and knowledge from one's schooling and/or upbringing. Crystallized intelligence can be formed from experience or information and also relies on memory, in particular, long-term memory (Knox, 1997).

Notably, intelligence measures are often used interchangeably with other decision-making activities. For example, many researchers view reasoning and problem solving are synonymous with fluid intelligence (Diamond, 2013), and others group reasoning and crystallized intelligence together as a closely-related construct (Lim and Dinges, 2010).

2.5.2 Measuring Higher-Order Cognitive Functions

This section describes tasks used to measure higher-order cognitive functions. We divide the tests into three categories: (i) cognitive flexibility, (ii) fluid intelligence, and (iii) crystallized intelligence.

I. Wisconsin Card Sorting Task. Measurement of cognitive flexibility often involves a series of set-shifting tasks. A prominent example of these is the Wisconsin Card Sort Task, in which participants are provided with a deck of cards, each of which can be sorted by color, shape, or number (Berg, 1948; Grant and Berg, 1948). The object here is for the participants to learn the correct sorting criterion based on feedback provided by the experimenter as to whether they have sorted the card correctly or not. In this task, however, the rules change periodically and without notification, such that participants must learn to change the sorting rule based on the feedback they receive. In it's standard form, the task requires the ability to read and understand numbers, however it can be adjusted to only include color and shape[4]. On the other hand, it is easy to explain and can be conducted electronically or with paper cards, making it practical in field settings.

II. Raven's (Progressive) Matrices Test. The most common and universally-accepted measure of fluid intelligence (and a frequent component of IQ tests) is the Raven's Matrices Test, named after the British psychologist John Raven, who developed the test almost eighty years ago (Raven, 1936, 2000). In this test, researchers ask participants to consider a main figure that is missing a section. The goal of the task is to complete the missing section by making the appropriate choice from a set of (typically 6) multiple-choice options that will complete the figure following a logical pattern. Easier versions of Raven's Matrices involve simple matching tasks such

[4] See, for instance, "Berg's Card Sorting Test," the Psychology Experiment Building Langauge (PEBL) computerized version of the task Wisconsin Card Sorting Task (PEBL, 2008–2010)

as identifying the shape that matches the other shapes in the figure, while more difficult puzzles require participants to solve an analytical problem or apply multiple logical rules (Prabhakaran et al., 1997). While a traditional Raven's Matrices set contains around 60 such trials, more recent studies aiming to use that include this task as part of a larger battery of tasks only fewer trials, often roughly 10-12 items (Mani et al., 2013; Raven, 2000). Researchers can alter the difficulty of a Raven's Matrices task, by increasing the number of multiple choice options available or the complexity of the rules participants must deduce to complete the puzzle.

III. Cattell Culture Fair Test. The Cattell Culture Fair test (Cattell, 1971) measures fluid intelligence (Unsworth et al., 2014). It is composed of four timed subtests, completed back-to-back, with participants allowed 2.5 to 4 minutes for each. The four subtests are as follows:

1. Series: Participants are shown incomplete series of abstract shapes and figures as well as potential answers that could complete the series. They are then asked to choose the response that best completes the series among the potential set of answers.

2. Classifications: Participants are again shown abstract shapes and figures in a set of five, and are asked to select the two figures that differ from the other three figures.

3. Matrices: Participants are shown incomplete matrices, again with abstract figures and shapes, as well as potential choices to complete the series. They are asked to choose the answer that best completes the matrix by inferring the pattern of objects within the matrix.

4. Conditions: Participants are shown abstract figures with lines and a single dot (e.g. a circle with a dot just to the left of it) and asked to infer the relationship between the dot and lines. They are presented with alternative figures with lines and a dot and asked to choose the one that best fulfills the same relationship.

The CATTELL score is the sum of all correct answers across subtests. This test is often generally completed on paper versus electronically and it does not require literacy or numeracy, making it easy to conduct in field settings.

IV. Wechsler Adult Intelligence Tests (WAIS). Researchers frequently use this test to measure both fluid and crystallized intelligence. Composed of 11 subtests, the WAIS consists of both a verbal and a "performance" component. The verbal sections include vocabulary, digit span, comprehension, and arithmetic. The performance sections include picture completion and arrangement, object assembly, etc. There are three variants of *Wechsler Intelligence Tests*: i) adult; ii) young children; iii) older children, each of varying difficulty. As described above, tasks that measure to crystallized intelligence rely on previous knowledge. As a result, performance on subtests that involve vocabulary or sentence completion can be limited by language skills, making implementation and interpretation difficult in many developing country settings. The test has been translated into over twenty languages to date.

3 Impact of Poverty on Cognitive Function

Although it may seem counter-intuitive that a person's fundamental "capacity" can be altered by his or her circumstances, there is a small but growing literature that demonstrates poverty can and does impact cognition in a variety of ways. This section briefly discusses some of the factors associated with poverty that have been shown to impact cognitive function and provides a non-exhaustive introduction to other aspects of life in poverty for which the evidence is more limited but suggestive of potential negative impacts and which warrant further investigation.

3.1 Malnutrition

Malnutrition has, throughout history, been associated with poverty. This relationship is still present today with one-seventh of the world's population remains below the level of caloric intake recommended by health professionals, and the vast majority of these individuals are among the poor in developing countries (Food and Agricultural Organization of the United Nations, 2011). Economists have studied this relationship over over 60 years, modeling nutrition as both consumption and an input into physical productivity (Leibenstein, 1957; Bliss and Stern, 1978; Stiglitz, 1976; Dasgupta and Ray, 1986). However, too little food may impact not only physical function, but also mental function: thoughts may become lethargic, attention difficult to sustain, and temptations harder to resist (Fonseca-Azevedo and Herculano-Houzel, 2012; Gailliot and Schmeichel, 2007; Danziger and Avnaim-Pesso, 2011; Baumeister and Vohs, 2007; US Army Institute of Environmental Medicine, 1987).

Schofield (2014) tests this idea with a randomized trial which examines the impact of additional calories on measures of cognitive function among low-BMI cycle-rickshaw drivers in India over a five-week period. Study participants undertook a battery of both physical and cognitive tasks at the beginning and end of the study, as well as reporting their labor supply and earnings daily throughout the study. Beyond improving labor-market outcomes, individuals with higher caloric intake showed an almost immediate 12 percent improvement in performance on the laboratory-based cognitive tasks, a gain that was sustained at the 5th week. In addition, these changes also manifested in a real-world effort discounting task in which participants could choose to provide no labor and earn nothing, or to take a journey with a lighter load today or a heavier load tomorrow, with both trips earning the same payment tomorrow. In this decision, treated participants were

25 percent more likely to opt to take the journey today rather than delay until tomorrow at the cost of a more difficult trip, suggesting a meaningful reduction in discount rates for effort in their work.

3.2 Excessive Alcohol Consumption

Excessive alcohol consumption has long been associated with poverty (Fisher, 1930), but the economic consequences remain poorly understood. "Alcohol myopia" theory offers insights into the effects of alcohol on human behavior (Steele and Josephs, 1990). This theory posits that the narrowing effect on attention is a defining feature of alcohol which, in turn, causes individuals to focus on simple, present, and salient cues. Viewed through the lens of this paper, alcohol consumption lowers attention and inhibitory control.

Schilbach (2015) conducted a three-week field experiment which demonstrated that such cognitive effects can translate into economically-meaningful real-world consequences. In this study, a reduction in daytime drinking among low-income workers in Chennai driven by randomly assigned financial incentives increased individuals' daily savings at a study office by 60 percent compared to a control group that received similar average study payments independent of their alcohol consumption. A simple calibration exercise suggests that these effects are not purely mechanical, i.e. individuals do not simply save more as a consequence of increased earnings. This argument is further supported by the fact that sobriety incentives and the commitment savings feature were substitutes in terms of their effect on savings.

3.3 Monetary Concerns

One obvious consequence of being poor is having less money to buy things. Less obviously, being poor also means having to spend more of one's cognitive resources managing what little money one does have. The poor must manage sporadic income and constantly make difficult trade-offs between expenses. Even outside of financial decision-making, preoccupation with money and budgeting can act as a distraction, in effect taxing mental resources.

Mani et al. (2013) use two distinct but complementary designs to establish the causal link between poverty and mental function. In the first study, they experimentally induce participants to think about everyday financial demands. For the rich participants, these thoughts are inconsequential. However, for the poor, inducing these thoughts can trigger persisting concern and distraction, with corresponding negative impacts on cognitive performance. The second study uses quasi-experimental variation in actual wealth over time. Agricultural income is highly variable, with Indian sugar cane farmers receiving income just once a year at harvest time. Because it is difficult to smooth their consumption across the year, they experience cycles of poverty—poorer before harvest and richer after—generating the opportunity to compare the cognitive capacity of a given individual across both "rich" and "poor" states (the authors rule out competing explanations, such as nutrition or work effort). Both studies show large and direct negative impacts of poverty on bandwidth; when one is poor, economic challenges are not just economic, but also cognitive. Constant trade-offs and difficult decisions tax scarce cognitive resources even further.

Hoel et al. (2016) also provide evidence of poverty's impact on cognition and preferences, in particular, poverty's impact on rates of time preference. In their sample of Ethiopian University students, less well-off students are more susceptible to depletion effects that are experimentally induced by undertaking a depleting cognitive activity (the Stroop task, described previously).

3.4 Physical Pain

Physical pain disproportionally impacts the lives of the worlds' poor, potentially caused by heavy physical labor, uncomfortable living conditions, and limited access to adequate health care and pain-management tools (Poleshuck and Green, 2008; Case and Deaton, 2015). Further, recent evidence suggests that economic insecurity in itself may generate physical pain and lead to reduced pain tolerance (Chou et al., 2016). A body of evidence demonstrates that pain can negatively affect various cognitive domains including attention, learning, memory, speed of information processing, psychomotor ability, and one's capacity to self-regulate, a core facet of executive function and central component of one's ability to inhibit actions and behaviors (Moriarty et al., 2011; Nes et al., 2009). Pain can also make it difficult for individuals to focus, interfering with one's thought process at inopportune moments and potentially competing for limited cognitive resources (Eccleston and Crombez, 1999).

Given these impacts on cognitive function, we hypothesize that pain is likely to affect decision making and labor market productivity. However, to date, little evidence exists about how these cognitive changes impact economic decision making. In one study, Kuhnen and Knutson (2005) found that people make more suboptimal financial decisions and are more risk averse after the anterior insula, the part of the brain that reacts to pain, is activated. Although only suggestive rather than conclusive, these types of changes may also hinder important decisions faced by many of the world's poor such as whether to send a child to school or whether to purchase health or rain insurance.

3.5 Sleep Deprivation

While inadequate sleep is a widespread problem across the globe, the poor in particular may not sleep well, especially in urban areas and in developing countries (Patel et al., 2010; Center for Disease Control, 2015). Individuals in these environments are likely to experience sleep deprivation given the prevalence of ambient noise, heat, light, mosquitoes, stress, overcrowding, and overall uncomfortable physical conditions (Grandner et al., 2010; Patel et al., 2010). Moreover, suboptimal sleeping conditions may also hinder deep sleep, which is essential to cognitive functioning (Sadeh et al., 2002; Roehrs et al., 1994). Further, because the effects of sleep deprivation increase with the cumulative extent of the deprivation, these impacts may be especially far reaching among those with few options for "catching up" given poor sleep environments (Van Dongen et al., 2003; Basner et al., 2013).

A robust body of evidence demonstrates that sleep deprivation and low-quality sleep impairs cognition, including reduction in attention and vigilance and impairments to memory and logical reasoning (Lim and Dinges, 2010; Killgore, 2010; Philibert, 2005; Scott et al., 2006). Much less work has been done to document the impact of these cognitive changes on economic decision making and productivity. Notable exceptions include a series of papers by Dickinson and co-authors that demonstrate that acute sleep deprivation (such as a full night without sleep) has mixed effects on risk preferences (McKenna et al., 2007), reduces trust and trustworthiness (Dickinson and McElroy, 2016), and reduces iterative reasoning in a p-beauty game in US populations (Dickinson and McElroy, 2010). Much work remains to fully understand the decision-making consequences of sleep deprivation, particularly in developing-country contexts.

3.6 Environmental Factors

A variety of environmental factors including noise, heat, and air pollution may also tax cognitive function. Although evidence is even more sparse than for the factors discussed above, these environmental irritants may have direct and indirect impacts on the poor, especially in the developing world and in particular in urban areas where exposure to these environmental irritants is often high (World Bank, 2015).

Noise pollution. In urban and developing environments, frequent noise pollution from cars horns honking, dogs barking, or crowds chattering can make it difficult to focus and perform any given task at hand. Studies of noise levels in cities in developing countries have found noise levels significantly above WHO recommended levels (Jamir et al., 2014; Jamrah et al., 2006; Zannin et al., 2002; Oyedepo and Saadu, 2009; Mehdi et al., 2011). In lab and field settings, increases in noise may not only induce anxiety and affect mood, but may also impair performance on cognitive tasks, particularly those that require attention and memory (Szalma and Hancock, 2011; Hygge et al., 2003; Boman et al., 2003; Enmarker et al., 2006). Noise can increase the mental workloaded needed for a particular situation by acting as an annoyance or stressor, in effect limiting the available cognitive resources (Becker et al., 1995). Further, there is also suggestive evidence that prolonged exposure to noise may impact working memory (Hockey, 1986; Szalma and Hancock, 2011). Children are at an additionally increased risk of the negative impact of noise exposure and show impairments in reading comprehension, attention, and memory (Stansfeld et al., 2005; Clark and Stansfeld, 2007; Hygge et al., 2002). Despite these indications of impacts on cognition, there is a dearth of evidence regarding the potential downstream impacts of noise pollution on decisions and productivity.

Heat. Similarly, excessive heat has the potential to impede cognitive function and impair motivation. This factor and its potential impacts are particularly relevant to life in developing countries, where the tropical environments and the lack of air conditioning make oppressive heat a near constant for many individuals. Existing evidence suggests that when exposed to an uncomfortably high temperature, reaction time and accuracy on attention, vigilance, and inhibitory control tasks are compromised (Simmons et al., 2008; Mazloumi et al., 2014). Moreover, exposure to excessive heat can impact productivity in manual work when the body is unable to maintain the appropriate core temperature (Kjellstrom et al., 2009). At the macro level, countries in hot climates have lower total agricultural output and economic growth, which could be partially explained by workers' reduced cognitive functioning (Dell et al., 2012). As global climate shifts continue to occur, studying these causal impacts will become even more central, with the majority of the burden borne by those in developing countries (Intergovernmental Panel on Climate Change, 2014). Although few studies to date map the entire causal chain from extreme heat to economic decisions and outcomes, recent research explores the effects of oppressive heat on downstream effects such as reduced worker productivity in developing settings (Burke et al., 2015; Dell et al., 2012; Jones and Olken, 2010; Hsiang, 2010) and to an extent in developed settings (Deryugina and Hsiang, 2014; Cachon et al., 2012).

Air pollution. The prevalence of less energy-efficient technologies and the lack of strong enforcement mechanisms for pollution regulations make high levels of air pollution common for many individuals living in urban developing environments (McGranahan and Murray, eds, 2003). Not only do pollutants harm physical health (Seaton et al., 1995; Pope, 2000; Ghio et al., 2000) and decrease life expectancy (Greenstone et al., 2015; World Health Organization, 2014; Lim et al., 2012), but there is also suggestive evidence that air pollution may be linked to significantly reduced worker productivity (Chang et al., 2016; Adhvaryu et al., 2014) and cognitive impairments in domains including attention, processing speed, working memory, and verbal memory (Tzivian et al., 2015; Lavy et al., 2014; Weuve et al., 2012; Power et al., 2011; Franco Suglia et al., 2008).

3.7 Stress and Depression

Stress and depression are widely prevalent across the globe - the World Health Organization (WHO) estimates that 350 million people globally suffer from depression (World Health Organization, 2016). Moreover, there is reason to believe that the poor are disproportionately likely to suffer from these ailments. Income and socioeconomic status have well-known correlations with stress and anxiety (Chen et al., 2010; Fernald and Gunnar, 2009; Evans and English, 2002; Lupien et al., 2001), with levels of the stress hormone cortisol (Cohen et al., 2006; Li et al., 2007; Saridjana et al., 2010), and with depression (Lund et al., 2010; WHO, 2001). Recent research using both natural experiments and randomized field experiments provides evidence that this relationship is causal, i.e. low income increases stress levels. In a recent study, Chemin et al. (2016) examine the effect of negative income shocks on stress using random rainfall shocks in Kenya to study changes in the stress hormone cortisol. Farmers who are more likely to be financially burdened by rainfall shocks exhibit increased measures of cortisol following these shocks. This relationship is not found in non-farmers, who are not as financially dependent on rainfall levels, and is less pronounced amongst farmers who have a second source of income compared with those who are solely dependent on agriculture. RCTs support these findings showing that a *reduction* in poverty caused by cash transfers reduces both stress and depression (Haushofer and Shapiro, 2016; Baird et al., 2013; Ozer et al., 2011; Fernald and Gunnar, 2009).

A number of studies show that inducing stress in laboratory settings can increase risk aversion (Kandasamya et al., 2013; Mather et al., 2009; Porcelli and Delgado, 2009; Cahlíková and Cingl, 2016; Lighthall et al., 2009). However, the evidence on stress' impact on time discounting is mixed (Cornelisse et al., 2014; Haushofer et al., 2013, 2015). Furthermore, chronic stress in childhood is inversely related to working memory in adults (Evans and Schamberg, 2009). Researchers have only recently begun to study the effects of depression on economic decision making, with several studies currently in the field. While these initial results focused primarily on short-run impacts of stress and depression are interesting, much more evidence is needed to understand the how these factors affect economic outcomes outside of laboratory settings. Moreover, most individuals tend to be exposed to poverty for extended periods of time, suggesting that studies to understand the longer-term impact of chronic stress and depression on economic outcomes are particularly promising avenues of research.

4 Impact of Cognitive Functions on Economic Outcomes

This section discusses the relationship between cognitive function and economic outcomes, with subsections dedicated to each of the areas of cognitive function covered in Section 2. In each subsection, we begin by discussing the existing evidence, both theoretical and empirical, for such impacts. Then we provide conceptual background on how changes in that area of cognitive function may impact economic outcomes in ways which have yet to be studied. Importantly, these discussions are not exhaustive; the number of potential pathways is sufficiently vast that we will only highlight a select set of illustrative examples in each area.

4.1 Attention

Attention, and its role in economic life, has generated growing interest in recent years. Economists have recognized that attention is a scarce resource, creating very real trade-offs. We first briefly review four modeling approaches of attention in economics and discuss the existing empirical evidence in support of each model. We then outline other outcomes that may be the result of attentional constraints, making them particularly promising directions for future research.

4.1.1 Theoretical Models of Attention

Four main strands of research modeling the role of attention in shaping economic behaviors have been developed. Each is discussed in more detail below.

I. Rational Inattention. Consistent with evidence from cognitive psychology research, the rational inattention literature considers attention to be a limited resource. Optimizing agents subject to attentional constraints allocate their available attention among competing sources of differing value. Most prominently in this literature, Sims (1998, 2003) proposes a model of limited attention as an information flow with a bound, where information is quantified as a reduction in uncertainty that comes at a cost. This model has widespread applicability to many decisions. Among other topics, Sims's rational inattention model has been applied to price setting (Woodford, 2012; Maćkowiak and Wiederholl, 2009; Matějka, 2016), consumption versus savings problems with constant (Sims, 2006; Luo, 2008) and variable interest rates (Maćkowiak and Wiederhol, 2015), portfolio management (Van Nieuwerburgh and Veldkamp, 2009; Mondria, 2010), political campaigns (Gul and Pesendorfer, 2012), and discrimination (Bartoš et al., 2016). To the best of our knowledge, however, direct tests of these models—e.g. by considering the impact of increases or decreases in attention on the outcomes of interest—have not been conducted to date.

II. Sparsity. Gabaix (2014) presents a model of bounded rationality in which individuals "sparsely maximize" or only pay attention to certain attributes. In this framework, an agent faces a choice of actions and must choose among them to maximize her utility, with her optimal action dependent on multiple variables. The agent uses a two-step algorithm to choose her utility-maximizing action. First, she chooses a "sparse" model of the world by ignoring many of the variables that could affect her optimal action. Second, she chooses a boundedly-rational action with this endogenously-chosen sparse model of the world.[5]

For each decision a person faces, there may be hundreds of relevant attributes, and it would be difficult, if not impossible, to take each of these into account. One potential consequence of a consumer choosing a "sparse" model of the world is the "stickiness" of choices and overweighting of default options in organ donation rates (Johnson and Goldstein, 2003), in retirement savings decisions (Madrian and Shea, 2001; Choi et al., 2006; Beshears et al., 2009), and in insurance markets (Handel, 2013; Handel and Kolstad, 2015; Bhargava et al., 2015), even when another option strictly dominates the default or previously chosen option.[6]

III. Salience. A third strand of theory directly models the salience of different attributes (prices, product characteristics, etc.) for different options in an agent's choice set and environment. In these models, salient attributes are defined as attributes that consumers disproportionately focus on and therefore overweight in their decision-making process. The key questions in such models are then what influences which attributes individuals focus on, and which attributes are salient in different environments. Three models of salience have been proposed to date:

(I) Bordalo et al. (2012, 2013) emphasize salience as a driver of choice. They present a model of salience in which an attribute of an option attracts more attention when it is significantly different, or "stands out", relative to the average attributes in an individual's choice set. That is, *relative* differences in attributes (in terms of utility) influence salience.

(II) Kőszegi and Szeidl (2013) develop a model of focus in which consumers focus more on attributes in which options generate a wider range of consumption utility. The model indicates that consumers are more likely to choose an option if its advantages are concentrated in fewer attributes, a "bias towards concentration."

(III) In contrast, Bushong et al. (2016) assume that the wider the range of utility for certain attributes, the *less* one attends to fixed utility differences.

IV. Selective Attention. In a fourth strand of the economics literature on inattention, Schwartzstein (2014) details how selective attention can have *persistent* effects on belief formation and learning. Underlying Schwartzstein's model is the idea that what an agent attends to today is dependent on his or her current beliefs. Following from this, what the agent attends to today will then also affect his/her beliefs in the future. In short, given incorrect initial beliefs, this attentional

[5] Gabaix expands this work to solve dynamic programming problems (Gabaix, 2016).

[6] While inattention likely plays a part in stickiness and the overweighting of defaults, other concerns likely play into "stickiness" as well, such as information availability and salience.

strategy can lead to a failure to recognize important predictors or patterns, leading individuals to overlook key factors in their decision making consistently and over long periods.

To date, there is only limited empirical evidence directly testing the predictions of these models, and, in particular, testing the predictions of these models against each other. As a result, it is likely too early to clearly predict how decreases in attentional constraints among the poor affect their choices. However, one natural hypothesis is that an increase in attention (e.g. due to improved sleep) reduces the biases in choice the models discussed above predict.

4.1.2 Existing Empirical Evidence

Empirical evidence for models of attention can be found in a number of realms, including technology adoption, shrouded attributes, productivity and savings. Each of these is discussed in further detail below.

Technology Adoption. Hanna et al. (2014) apply Schwartzstein's model to technology adoption in seaweed farming, and demonstrate how even when people have repeated experience with a decision they may fail to notice important product attributes, and thus may fall continuously away from the production frontier. Similarly, Datta and Mullainathan (2014) note that programs to encourage the adoption of technology often fail and that it is essential that new users are attentive to certain features of the technology to use it effectively. Further, the selection attention model has been used to explain low usage or non-adoption of technology or best practices. For instance, historically, there was delayed recognition of the importance of sterilizing operating rooms to prevent infections despite access to relevant data (Gawande, 2004; Nuland, 2004). Doctors had false beliefs about other causes of infection that prevented them from considering, or paying attention to, a simple, effective intervention such as hand washing. In a similar manner, Bloom et al. (2013) show that managers failed to adopt best practices in the Indian textile industry, despite natural variation pointing to the importance of attributes contributing to best practices.

Shrouded Attributes and Salience. A number of studies find that consumers neglect certain product characteristics and taxes, referred to as "shrouded attributes" (Gabaix and Laibson, 2006). Accordingly, increasing or decreasing salience of these attributes can significantly effect sales (Chetty et al., 2009; Gallagher and Muehlegger, 2011), labor supply, and earnings behavior (Chetty and Saez, 2013). In a study of commodity tax salience, Chetty et al. (2009) find that a small increase in tax that is included in posted-prices reduces demand more than when that tax is added to the price at the register. Although consumers are aware that the taxes exist in the abstract (based on survey data), they fail to attend fully to these less-salient taxes at the time of purchase.

Productivity. Existing theoretical work also links attention to poverty traps. Banerjee and Mullainathan (2008) present a model of poverty and attention based on the idea of attention scarcity. They note that if the poor have more issues requiring their attention at home because they are unable to purchase attention-saving technologies (e.g. having water delivered instead of having to remember to go collect it), they may be distracted and unable to pay full attention to their work, impeding their productivity. While this is an intriguing hypothesis, direct empirical evidence on such effects is scarce.

4.1.3 Other Potential Pathways

Despite the fact that attention receives more focus in the economics literature than most areas of cognition, there remain many unexplored ways in which constraints on attention may impact the lives of the poor.

Workplace and Traffic Accidents. For example, workplace or traffic accidents are both substantial concerns among the poor, and are potentially driven in part by lapses in attention. Moreover, the consequences of attentional lapses may be larger for the poor, who often lack the safety nets or precautions that exist in more developed economies. For example, imagine a worker on a factory assembly line monotonously operating a machine, whose mind wanders off for a split second at the wrong moment. In many resource-poor settings, such a lapse often results in a serious accident. Of course the same is possible in developed contexts, but many precautions such as automatic shutdown mechanisms or safety equipment often prevent the same lapse from having such extreme consequences. Similarly, consider the dire consequences of a driver who loses focus on a highway after hours of commuting every day. In fact, 41% of car crashes in the US are estimated to be the result of recognition errors, including inattention (USDT, 2008). Yet, these lapse rates are likely to be significantly higher in developing countries where factors that impact lapses, such as sleep deprivation, are more prevalent and where the mechanisms to prevent such accidents, such as rumble strips, are less likely to be present.

Childcare. Although the examples above focus on salient and distinct lapses with immediate and directly-linked consequences, lapses in attention that are much more subtle and long-term may also have substantial negative consequences. For example, consider attending to one's children to ensure that they complete their homework, or that they stay healthy and safe. Although a single lapse may not have significant consequences, the effects are likely to compound and may have severe long-run welfare effects for the child, including increasing the likelihood of inter-generational transmission of poverty.

These examples are just some of many potential pathways of the impacts of attention. Much work remains to flesh out these pathways, their impacts, and heterogeneity in those effects.

4.2 Inhibitory Control

An important real-world aspect of inhibitory control is self-control – the ability to regulate one's behavior when faced with impulses and temptations in order to follow through on an intended plan. The study of self-control problems continues to receive enormous attention in the economics literature, including both theoretical and empirical work. Because several excellent reviews of this large body of work have been written recently (Frederick et al., 2002; DellaVigna, 2009; Bryan et al., 2010), we review the theoretical literature in less detail than in other sections.

4.2.1 Theoretical Models of Self-Control

To date, the two main strands of theoretical work on self-control that have been most influential are hyperbolic discounting and dual-self models.

Hyperbolic Discounting. Hyperbolic discounting theory is based on empirical findings that discounting is not time-invariant; rather individuals instead tend to put more weight on the present than on the future (Frederick et al., 2002). Laibson (1997) and O'Donoghue and Rabin (1999) formalize quasi-hyperbolic discounting models of these observed preferences, that build on work by Strotz (1956), Phelps and Pollak (1968), and Akerlof (1991). These models have two parameters governing intertemporal preferences—δ, the standard long-run discount factor, and β, the short-run parameter which represent the desire for immediate gratification. When $\beta < 1$, discounting between the present and future periods is higher than between future time periods and the agent's preferences are time-inconsistent. Whether or not a decision-maker is aware of his or her future preferences can have important effects on behavior. O'Donoghue and Rabin (1999, 2001) model expectations of future time preferences, and define three types of agents: (i) sophisticated agents who know they will exhibit present-bias in the future, (ii) naïve agents, who falsely believe their future self is not present-biased, and (iii) partially naïve agents who know that they exhibit self-control issues, but underestimate the extent of the bias, causing these agents to be overconfident about their future level of self-control.

Dual-Self Models. The other prominent strand of theoretical work on self-control focuses on dual-self models (Fudenberg and Levine, 2006; Gul and Pesendorfer, 2001, 2004). Dual-self models differ in structure, but they all include a short-run self and a long-run self, which often find themselves in conflict. The short-run doer is myopic and only concerned with the present, while the long-run planner is concerned with lifetime utility (Thaler and Shefrin, 1981). The long-run planner can exert influence over the short-run doer, but this comes at a cognitive cost (Fudenberg and Levine, 2006). In a different type of dual-self model, the temptation-preference model of Gul and Pesendorfer (2001, 2004), agents consider preferences among choice sets. While most models of intertemporal choice assume that options not chosen are irrelevant to utility, Gul and Pesendorfer's model posits that agents experience disutility from not choosing the most tempting current option. Thus agents can avoid temptation, but there is an associated cost to this avoidance. Therefore, agents can benefit when they remove tempting options from their choice sets.

A main distinction between these two frameworks is whether agents care about future self-control costs. Though agents may be aware of these costs, they do not care about them in quasi-hyperbolic discounting models, while they do care about these costs in dual-self models. Despite their differences, both models predict a demand for commitment.

4.2.2 Existing Empirical Evidence

Lack of self-control can contribute to procrastination and the tendency to put immediate desires above long-term goals, thus influencing a number of decisions that are of interest to economists.

Borrowing, Saving, and Investing. A relatively large body of evidence suggests that self-control problems interfere with low-income individuals' intertemporal choice.[7] A number of studies detail instances in which the poor fail to take advantage of small and divisible high-return investment opportunities.[8] Moreover, the poor are more likely to borrow at high interest rates (Aleem, 1990; Karlan and Mullainathan, 2010).[9] Beyond this suggestive evidence, several studies show the impact of self-control on individuals' consumption-savings choices. Ashraf et al. (2006) find high take-up rates and significantly increased savings for a commitment savings product in the Philippines, which reveals a causal impact of self-control problems on savings behavior. Dupas and Robinson (2013) run a field experiment in Kenya and find that study participants as a whole increase savings and benefit from access to simple, safe, savings accounts, earmarked savings

[7] See Haushofer and Fehr (2014) for a discussion of poverty and time discounting.

[8] A number of papers suggest that the poor opt for present spending over potential high-return investments. This literature includes work by de Mel et al. (2009) on micro-enterprise in Sri Lanka, Duflo et al. (2011) on fertilizer usage in Kenya, Kremer et al. (2013) on Kenyan retail shops, and Udry and Anagol (2006) on agricultural investment in Ghana. Banerjee and Duflo (2011) provide similar similar findings in survey results.

[9] Banerjee and Mullainathan (2010) also provide evidence that despite the high interest rates in developing countries, loans are taken out routinely rather than simply being used for emergencies.

accounts, and Rotating Savings and Credit Associations (ROSCAs). However, amongst study participants with time-inconsistent preferences, access to the simple savings account and earmarked savings account did not increase savings, while access to ROSCAs did. This suggests that providing access to safe savings technologies is not sufficient to increase savings in this group, and another factor (e.g. societal pressure) might be needed to encourage those with time-inconsistent preferences to save.[10]

Consumption Choices. Beyond distortions in intertemporal choice, there is also evidence that self-control problems interfere with individuals' consumption choices within periods. Such evidence exists in particular for addictive goods. In line with Gruber and Kőszegi (2001), Giné et al. (2010) find demand for a voluntary commitment product for smoking cessation in the Philippines, which produced moderate improvements in long-term smoking cessation. In a field study among low-income workers in India, Schilbach (2015) finds that about half of study participants exhibit demand for commitment to increase their sobriety, again revealing self-control problems. Moreover, about a third of participants were willing to give up at least ten percent of their daily incomes in order to receive incentives to remain sober.

Productivity. People who recognize that they suffer from self-control problems may seek commitment devices, self-imposed or otherwise, to improve productivity. Ariely and Wertenbroch (2002) run experiments in which students are allowed to pre-emptively set due dates for school assignments, and find that students are willing to self-impose costly deadlines. While these self-imposed deadlines did improve overall performance, these deadlines weren't set optimally. In a real-world work setting, Kaur et al. (2015) find significant demand for commitment among data-entry workers in India. Employees at a data-entry firm are offered weakly dominated "commitment" contracts, which pay less than the standard piece rate if a production target is not met, and the standard piece rate if the production target is met. The authors find substantial demand for commitment among the workers and found that contracts with commitment resulted in significantly increased productivity and payment. Additionally, they found other evidence of self-control concerns such as effort increases on days closer to the worker's payday.

4.2.3 Other Potential Pathways

While the study of self-control in poverty is already extensive, there are many ways in which potential cognitive changes that alter self-control can impact the lives of the poor.

[10]Similarly, Shipton (1992) finds demand for "lockbox" savings accounts in Gambia, and a number of studies on ROSCAs provide evidence that these associations are used as a means to improve self-control in savings behavior (Aliber, 2001; Anderson and Baland, 2002; Gugerty, 2007). See Ambeca and Treich (2007) and Basu (2014) for theory.

Health. One of these areas is health – in addition to refraining from addictive substances that can harm health, self-control is essential for other health factors, such as attending yearly check-ups at the doctor and maintaining a healthy weight. Rates of overweight and obesity are rising rapidly in many developing countries. As calories become less expensive and more readily and consistently available, the poor will require substantial self-control in order to regulate intake and maintain a healthy weight.

Educational Attainment. Educational attainment is another area in which self-control can have important implications. Students exercise self-control when they get up in the morning to attend class, pay attention to the teacher, study new material, and complete homework assignments. Deficiencies in self-control are likely to impact academic attendance, performance, and eventual achievement.

Crime. One prominent theory on crime, the "self-control" or "general" theory of crime, posits that low levels of individual self-control are the main factor driving criminal behavior (Gottfredson and Hirschi, 1990). This view has received empirical support in the criminology literature (Pratt and Cullen, 2000).

As in the case of attention, the costs of lapses in self-control are also likely to be more severe for those living in poverty. Splurging on a tasty snack item or a new item of clothing is hardly a life-changing event for the wealthy. Among the poor, however, these moments where self-control is lacking can have far-reaching consequences, for example, leading to expensive cycles of debt as described above.

4.3 Memory

The literature in economics on memory is both diverse and relatively recent. Below we highlight three theoretical models of memory's impact on economic outcomes as well as related empirical evidence, which mainly focuses on impacts on health and savings.

4.3.1 Theoretical Models of Memory

While economic theory on memory is more limited as compared to attention or inhibitory control, a number of models do exist. We detail three of these theoretical models on memory below.

Rehearsal and Associativeness. Mullainathan (2002) provides an economic model of memory limitations that can explain certain biases and empirical puzzles (e.g. over- or under-reaction to news in financial markets). In doing so, he draws on two constructs from the psychological and biological literatures on memory - *rehearsal*, the idea that it is easier to remember an event after having remembered it once before, and *associativeness*, the idea that it is easier to recall an event that is similar to current events. Both of these concepts affect how accessible a given memory is, and can thus be explanations for observed behavioral biases.

The Cost of Keeping Track. Haushofer (2015) shows that keeping track of incomplete tasks generates costs to the agent in the form of financial consequences (e.g. late fees) and/or psychological consequences of keeping the task in mind. Haushofer models these costs as a lump sum, and shows that these costs explain a number of behavioral discounting phenomena that can lead people to "pre-crastinate" or incur a loss in the present rather than in the future. Haushofer shows this empirically drawing on research conducted in Kenya, which confirms that people often pre-crastinate rather than waiting to act on future profitable opportunities which they may forget. Haushofer notes that this model of memory can be valuable in many settings within development economics – for example, by providing options that do not require people to pay the cost of keeping track – such as providing chlorine at the place where water is collected rather than in the home, which has been shown to improve usage (Kremer et al., 2009).

Memory and Procrastination. Ericson (2016) notes that while reminders can have significant effects on actions, deadlines, which should prompt agents to overcome present bias and act, are often ignored, even when such actions lead to substantial losses.[11] Ericson shows that the interaction of present-bias and memory can explain these phenomena. His model suggests that anticipated reminders, such as deadlines, can induce procrastination, while unexpected reminders might bring welfare-inducing actions to the top of mind, spurring action.

4.3.2 Empirical Evidence

A relatively large body of evidence demonstrates the importance of memory to economically important outcomes by providing evidence that reminders can effectively alter agents' behaviors.

Health. A large share of the evidence on reminders stems from the medical literature, in particular the literature on medical adherence (see Haynes et al. (2008) and Vervloet et al. (2012) for overviews). A relatively robust finding from this literature is that reminders typically have a modest but meaningful impact on healthful behaviors including smoking cessation (Free et al.,

[11] For example, King (2004) finds that students fail to apply for financial aid by the deadlines, and Pechmann and Silk (2013) find that people do not submit rebates prior to their expiration.

2011), adherence to medication and treatment regimens (Pop-Eleches et al., 2011; Dulmen et al., 2007; Krishna et al., 2009), and preventive health behaviors such as sunscreen use (Armstrong et al., 2009).

Savings. Conducting an experiment with commitment savings customers in Bolivia, Peru, and the Philippines, Karlan et al. (2016a) show that reminders can also improve savings behavior. They vary the reminders sent to customers and find both that reminders increase savings and that reminders of specific future goals, which often require a high lumpy expense, are particularly effective at increasing savings. This evidence provides an interesting explanation related to memory and recall for low savings and suggests that reminding people of long-term goals can effectively alter behavior. Significant effects of reminders have also been found for loan repayments (Karlan et al., 2016b; Cadena and Schoar, 2011).

4.3.3 Other Potential Pathways

Memory also plays a central role in a wide range of other economic behaviors, as evidenced by the effectiveness of reminders in a wide variety of domains beyond the health applications above including donations (Damgaard and Gavert, 2014), appointment sign-ups (Altmann and Traxler, 2012) and show-ups (Guy et al., 2012), and rebate claims (Letzler and Tasoff, 2014), among other behaviors.

However, memory is central to economic outcomes beyond simply remembering to undertake tasks. In particular, working memory plays an important role in understanding language, doing mental math, updating information or actions, and considering alternatives. Impediments to working memory are associated with increased delay discounting and impulsiveness (Hinson et al., 2003). The ability to consider alternatives and make prudent, rather than impulsive, decisions is essential for good decision making.

Although to the best of our knowledge unstudied to date, low literacy or illiteracy may also impose a significant tax on memory. If one is unable to write down instructions, directions, or other key information and is instead forced to keep it in mind, there are fewer attentional or working memory resources available to be devoted to other decisions and tasks. Take, for example, a farmer learning about a new fertilizer technology. Remembering the advice of an agricultural extension agent for a number of months and then recalling it at the appropriate time will either drain important cognitive resources or result in a loss of potentially valuable information. These burdens are largely shouldered by the poor due to their lower levels of literacy and numeracy.

4.4 Higher-Order Executive Functions

Economic theory on higher-order executive functions is more limited as compared to other components of cognitive function. However, we posit a number of areas where these functions may play an important role in behavior and decision making.

4.4.1 Theory

While the existing economics literature includes several conceptual models of how the three above areas of cognitive function can affect economic outcomes, there is no equivalent conceptual work on the impact of higher-order executive functions to date. We therefore focus on existing empirical work.

4.4.2 Empirical Evidence

There is substantially less evidence in the economics literature on what effects cognitive flexibility and intelligence may have on an agent's outcomes and behavior. We outline the available evidence below.

Optimization Behavior. Traditional economic theory suggests that agents optimize their choices or behaviors based on their individual preferences and constraints. Therefore, given the same choice set with the same constraints and information, agents should make the same utility-optimizing choice. However, research shows that this is not always the case, and that in certain situations decision making is inconsistent (Sippel, 1997; Février and Visser, 2004; Famulari, 1988). While this could be due to multiple causes—for instance, preferences shifting over time or indifference between options—recent research shows that cognitive ability may also be related to inconsistent or random decision making (Andersson et al., 2016).

Choi et al. (2014) test for consistency in utility maximization and find that consistency scores vary significantly within and across socioeconomic groups, with consistency particularly strongly related to wealth. Poorer individuals exhibit lower consistency even when controlling for unobserved constraints, preferences, and beliefs.

Insurance, Savings and Investments. Agents need to be able to imagine themselves in another state of the world – one in which they experience a negative shock or a benefit from an investment – in order to see the value of insurance and savings. Indeed, evidence that cognitive flexibility may affect savings behavior follows from the psychology literature. For instance, Christelis et al. (2010) show that low levels of cognitive flexibility are associated with both lower risk tolerance and lower ability to process and comprehend financial data, resulting in reduced stock market participation.

Financial decision-making requires the ability to make relatively complex calculations, which depend on intelligence and numeracy (Lusardi, 2012). Numeracy and basic financial literacy (e.g. basic understanding interest rates) have been found to have strong links with day-to-day financial management (Hilgert et al., 2003) and long-term financial outcomes such as savings, wealth, and portfolio management (see Lusardi and Mitchell (2011) for an overview). The elderly are particularly vulnerable to poor financial decisions given cognitive decline that comes with aging, including high rates of dementia or cognitive impairment – Agarwal et al. (2009) find that financial mistakes follow a U-shape pattern with respect to age, with the fewest mistakes made at age 53. Similarly, diminished cognitive ability due to aging has been found to affect insurance choices among the elderly. (Fang et al., 2008) find advantageous selection in the U.S. Medigap market and attribute this largely to cognitive ability (measured by questions on literacy, subtraction, recall and the Telephone Interview for Cognitive Status score). Medigap insurance can be beneficial for seniors with high expected healthcare costs, but lack of ability to understand insurance policies may result in seniors not enrolling in this program.

Further evidence on savings and investments suggests that broad measures of intelligence are negatively correlated with both impatience and risk aversion, potentially impacting economic outcomes through these channels as well (see Shamosh and Gray (2008) for a literature review on impatience and cognitive function). In a study of Chilean students with similar school backgrounds, Benjamin et al. (2013) find that higher standardized test scores (a potential, though flawed, measure of intelligence) are correlated with lower small-stakes risk aversion and short-run discounting, even when controlling for parental wealth and educational attainment. Frederick (2005) shows that performance on a number of cognitive ability tests is negatively correlated with both impatience and risk aversion.[12]. Expressed risk preferences can be influenced by the complexity of a given problem, which suggests a channel though which intelligence could play a role in risk aversion (Huck and Weizsäcker, 1999). In addition, there is a body of work that finds broad, general measures of intelligence to be negatively correlated with discount rates (Kirby et al., 2005; Silva and Gross, 2004; Jaroni et al., 2004). In these ways, poverty and the impairments to higher-order executive functions that result may impact decision making through other behavioral channels such as self-control.

Innovation. Psychologists widely regard cognitive flexibility to be an important aspect of both innovation and creativity (Chi, 1997; Jaušovec, 1991, 1994; Runco and Okuda, 1991; Thurston and

[12] Dohmen et al. (2010) replicate these findings in a large, representative sample, while Burks et al. (2010) find the same relationship in a large sample of participants with lower levels of cognitive ability. However, based on evidence from a large experiment in Denmark, Andersson et al. (2016) find that the negative relationship between risk aversion and cognitive ability may be spurious

Runco, 1999; Torrance, 1974). Cognitive flexibility can facilitate creativity, and thereby increase innovation by helping individuals see a problem from a new perspective and shift strategies to more efficiently solve a problem (Thurston and Runco, 1999; Okuda et al., 1991). Higher-order thinking can also enable individuals to switch between conceptual ideas and thus avoid getting stuck on one piece of a problem.

Labor Market Outomes. There is a wide body of literature that highlights the importance of cognitive skills, often measured by intelligence scores, in predicting wages (Murnane et al., 1995), on-the-job performance, and training success (Bishop, 1991), and schooling (Cawley et al., 2001b)[13]. Several studies replicate these findings in developing countries; researchers have found that cognitive skills have a postitive effect on total income and off-farm income in Ghana (Jolliffe, 1998) and have signigicant pay-offs in the rural wage labor market in Pakistan (Alderman et al., 1996; Behrman et al., 2008). Likewise, Boissiere et al. (1985) show earnings returns to literacy and numeracy skills in Tanzania and Kenya.

4.4.3 Other Potential Pathways.

In addition to the empirical evidence outlined above, we hypothesize that higher-order executive functions may play a role in other areas of economic interest.

Technology Adoption. One area in which higher-order executive functions may play a role is technology adoption. To be willing to adopt a given technology, agents must be willing and able to see themselves in another state of the world. This flexibility is essential as the investment needed to adopt a new technology generally takes place prior to the realization of benefits, making the ability to envision an alternative state of the world essential. In short, it is necessary to be able to imagine the potential value of the technology prior to adopting it.

Resilience. Cognitive flexibility is a key component of resilience. It allows individuals to reframe or reappraise a situation instead of getting stuck in a particular mindset, providing more potential solutions to a problem. Further, cognitive flexibility enables individuals to reevaluate and adjust their perceptions of difficult and traumatic events, which can help them to understand the trauma and recover from it. For example, after surviving a traumatic event, cognitive flexibility can enable an individual to maintain the belief that he or she will prevail despite the difficulties of life (e.g. "It was difficult that I lost my father at a young age, but it made me a stronger person.").

[13] Cawley et al. (2001a) provide a summary of the evidence on cognitive ability as a predictor of educational attainment and wages

Cooperation. Cognitive flexibility even has the potential to effect cooperation and interpersonal relationships. Consider interpersonal disagreements or conflicts – the ability to see the world through the eyes of others is often helpful in order to resolve conflict when there are different preferences or opinions. This, in turn, could have potential implications in models of household bargaining, social cohesion and trust, and workplace relationships.

5 Open Questions and Future Research Directions

Cognitive function and its implications for human behavior and economic outcomes are not poverty-specific, rather they are applicable in a much broader range of settings and across many income levels. However, cognitive function is particularly relevant to the study of development and poverty because poverty may be both a cause and a consequence of such changes. An adult's cognitive ability is traditionally considered fixed, but in fact newer evidence shows that it is variable and can be affected by circumstances. Poverty has associated hardships—lack of nutritious food, limited access to medical care, difficult working conditions, and the stress of paying bills—all of which have the potential to impair cognitive ability. Shifts in cognitive ability, in turn, can lead to diminished productivity and worse decision making, thus creating further poverty, a feedback loop which generates the potential for poverty traps.

Although evidence of this potential exists, much remains unknown regarding the exact nature of the relationships between areas of cognitive function and poverty, in both directions. This relative paucity of information generates an open and valuable area of research to pursue. *How* do poverty and environment shape cognitive function, and how does cognitive function shape economic outcomes? There are specific components of poverty that have already been studied and shown to affect cognitive ability, such as scarcity (Mani et al., 2013), nutrition (Schofield, 2014), and alcohol consumption (Schilbach, 2015).

Yet, numerous other components and correlates of poverty may affect cognitive function in ways that are not yet well understood, such as lack of sleep, chronic pain, noise or air pollution, and heat. Beyond these relationships, there are myriad other valuable directions of inquiry in this area to understand these relationships comprehensively, and in doing so, potentially inform both basic knowledge and policy. For example, do long-run aspects of poverty (e.g. childhood lead exposure) have different effects than short-term poverty spells? Exploring the components of poverty that can shift different executive functions will allow us to test predictions of the various economic models outlined earlier in the paper, allowing us to judge model fit and the magnitudes of potential effects of these changes in cognition.

A further area of high-value research is to develop our understanding of how cognitive functions correlate both between and within individuals. If these outcomes are highly correlated within an individual at a given point in time or within individuals with certain defining characteristics, it would provide useful information on potential causes of cognitive deficits and lead to substantial reductions in data-collection requirements. There is some evidence that different tests of cognitive ability are highly correlated— the literature indicates one can account for at least half of the variance between different cognitive tasks by a single general factor (Jensen, 1998; Lubinski, 2004; Spearman, 1927, 1904).

Seeking a deeper, more nuanced understanding of cognition has enormous potential to help us understand the causes and consequences of poverty. Although a broad topic with many overlapping aspects, cognition does consist of measureable and reasonably distinct components. In this paper we have outlined four components of cognition that are important to economics—attention, inhibitory control, memory and working memory, and higher-order executive functions, which include cognitive flexibility and fluid and crystallized intelligence. While we know a fair amount about how to measure cognition, we know far less about its influence on productivity and decision making. Now that we have the tools available, this is an area ripe for future research.

A Appendix

A.1 Summary Table of Cognitive Tasks

Task Name	Description	Background Needed	Ability to Manipulate Difficulty	Modes of Administration
Simple Attention				
Psychomotor Vigilance Task (PVT)	A task that measures the accuracy and reaction time of participants responding to a stimulus.	No	A little	Electronic Only
Complex Attention				
Concentration Endurance Test	A task that requires participants to view a continuous list of letters p and d, with up to two markings above and/or two markings below the letter. The participant has to cross out d's which are surrounded by exactly two markings.	In some forms affected by literacy	No	Paper or electronic
Inhibitory Control				
Hearts and Flowers Task	This task requires participants to learn a rule, and then switch to a second rule. Specifically, the screen is divided into two panels and either a heart or a flower is flashed onto one side of screen. Participants are first shown only hearts and are asked to click on the same side of the screen as the heart. They are then only shown flowers and are asked to click on the opposite side of the screen as the flowers. In a third trial, they are shown both hearts and flowers and must click on the appropriate side according to the stimulus.	No	Yes	Electronic Only
Eriksen Flanker Task	Participants are shown stimuli and are asked to only respond to the central stimuli, ignoring flanking stimuli around it.	Sometimes literacy is needed	A little	Electronic Only
Classic Stroop Task	A task in which participants see the name of a color printed in a different ink color, and the participant is asked to name the ink color (e.g. the word "green" is written in red ink and the participant is expected to reply with "red").	Literacy required	No	Paper or electronic
Spatial Stroop Task	Participants are shown arrows and told to press in the direction the arrow is pointing. Arrows are shown on different sides of the screen and participants must overcome prepotent tendency to automatically press on the side that the stimulus appears when the locations of the stimulus and the response are incongruent.	No	Yes	Electronic Only
Short-Term Memory				

Task Name	Description	Background Needed	Ability to Manipulate Difficulty	Modes of Administration
Forward-Digit Span Task	Participants are asked to listen to a list of numbers and repeat them back in the same order. Can be modified for subjects without numeracy to include objects in place of numbers.	Numeracy required in traditional version	Yes	Verbal, paper, or electronic
Corsi Block Task	Participants are shown a series of blocks, which are indicated one at a time by a change of color or pointing in a random sequence. Participants are then asked to click on or point to the blocks in the sequence just shown. A modified version of this task requires reordering the blocks by subjects, which measures working memory.	No	Yes	Paper or electronic
Working Memory				
Backward-Digit Span Task	Participants are asked to listen to a list of numbers and repeat them in numerical or reverse-numerical order. Can be modified for subjects without numeracy to include objects in place of numbers.	Numeracy required in traditional version	Yes	Verbal, paper, or electronic
Self-Ordered Pointing Task	Participants are shown a number of items (which could be physical items or different drawings or symbols) and asked to touch one item at a time, in any order, without repeating a choice while the items are scrambled in between turns. Researchers can leave identical items that remain stationary.	No	Yes	Using physical items, paper, or electronic
Cognitive Flexibility				
Wisconsin Card Sorting Task	Participants are provided with a deck of cards, each of which can be sorted by color, shape or number. Participant attempts to learn the correct sorting criterion based on feedback and is expected to switch sorting rules if they receive feedback that the rules have changed. The task can be modified for subjects without numeracy.	Numeracy required in traditional form	No	Paper or electronic
Educational differences can affect outcomes	Yes	Verbal, paper, or electronic		
Fluid Intelligence and Crystallized Intelligence				
Raven's matrices	Participants are shown visual geometric designs missing one piece and are given 6-8 choices and asked to pick the one the piece that represents the missing piece	No	Yes	Paper or electronic
Cattell Culture Fair Test	Participants complete four timed subtests completed back-to-back: series, classifications, matrices, and conditions. Each of these requires the subject to recognize patterns or implied rules.	No	Yes	Paper or electronic

Task Name	Description	Background Needed	Ability to Manipulate Difficulty	Modes of Administration
Wechsler Intelligence Test (WAIS)	Participants complete a verbal section covering vocabulary, digit span, comprehension, and arithmetic, and a performance section including picture completion/arrangement, object assembly, etc.	Literacy and numeracy required, educational differences can affect outcomes	Yes	Paper or electronic

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