Poverty and Cognitive Function*

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1 Introduction

While economic growth has lifted billions out of poverty in the span of a few generations, poverty still remains entrenched for millions around the globe despite many poverty alleviation efforts. One long standing explanation for its persistence is the possibility of poverty traps, or self-reinforcing cycles of poverty.

Theoretical models of such traps, often centered on nutrition in the earliest cases, have been central in development literature for over half a century (Mirrlees, 1975; Leibenstein, 1957; Bliss and Stern, 1978; Stiglitz, 1976; Dasgupta and Ray, 1986). This literature has expanded in many directions to consider the varying potential underlying forces and implications of such traps ranging from geographic characteristics, inter-generational transmission, pecuniary externalities, and even cultural forces (Jalan and Ravallion, 2002; Sachs, 2014; Currie and Almond, 2011; Fang and Loury, 2005; Barrett and Carter, 2013; Sachs, 2005). Despite the burgeoning literature in this space and the policy appeal of the potential to instigate virtuous and self-reinforcing cycles of income growth and wealth, the empirical evidence for such traps remains mixed (Barrett et al., 2016; Kraay and McKenzie, 2014; Banerjee and Duflo, 2011). Moreover, in the instances of actual evidence of such traps, their exact mechanisms remain unclear (See Banerjee et al. (2015); Bandiera et al. (2015)).

One potential underlying mechanism could be cognition. On one side of the potential trap, poverty may affect cognitive functions. Evidence is beginning to accumulate that cognitive functions are limited resources, which can be strained by poverty in various ways (Schilbach, Schofield and Mullainathan, 2016). First, simply being forced to make constant trade-offs with limited resources can act as a "load" on cognition (Mullainathan and Shafir, 2013). Second, in addition to capturing individuals' minds, poverty comes along with a number of material deprivations which may impede cognition further. 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, 2010b; Moriarty et al., 2011; Schofield, 2014; Schilbach, 2015). The resulting reductions in these 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.

The goal of this paper is to highlight cognitive function as a potential source of poverty traps and, in doing so, to facilitate further study of this potential 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 organized 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 space. Section 3 shifts

focus to the relevance of these areas of cognitive function to economic outcomes, and more broadly to development and the potential for feedback effects. The section also briefly highlights evidence of poverty's impact on each area of cognitive function. Section 4 highlights open questions and high value areas of future research in this space. Section 5 concludes.

2 Cognitive Functions

This section gives a brief general overview of cognitive functions. After this overview, we will discuss in detail four different aspects of cognitive function as well as canonical tasks to measure them. Additional detail on the cognitive functions included in this paper can be found in Lyon and Krasnegor (1996), Diamond (2013) and Suchy (2009).

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. All of these functions—e.g. movement, sensory input and interpretation—are important to daily functioning. However, there is one set of functional areas that is of particular relevance and interest to decision-making and economic life. Termed cognitive function 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 function is crucial to task performance and decision-making, and carries longer-term impacts such as reading literacy and school performance (Borella et al., 2010; Duncan et al., 2007).

Cognitive functions are top-down processes, initiated from the pre-frontal cortex in the brain, which are required for deliberate actions such as forming a goal, 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 sub-components to the specific neurological brain circuits required for different areas of functioning (Jurado and Rosselli, 2007). For example, a topic of debate is whether or not there is one unifying mechanism underlying the entire cognitive function construct, also known as the "Theory of Unity" (Kimberg et al., 1997; deFrias et al., 2006; Godefroy et al., 1999). While beliefs are wide-ranging, most researchers fall in the middle of this spectrum, taking the view that while there is no one unifying mechanism, broad classification of sub-components is possible (Miyaki et al., 2000). In this paper, we will utilize this middle-ground approach and focus on topics that are both generally agreed upon by cognitive psychologists and that we consider to be central to understanding cognition's role in economic life and economic outcomes.

With this overview is mind, we will focus on four generally agreed-upon areas of cognitive function:

(I) **Attention** is a fundamental aspect of cognition. It is the ability to focus on particular piece(s) of information by engaging in a selection process that allows incoming stimuli to be further processed. This could happen voluntarily or involuntarily. For example, we are alerted to sudden loud noises (involuntarily) or can comprehend a bullet point on a presentation slide (voluntarily), using attention. Attention is crucial in everyday functioning. Perhaps due to its key role in nearly all decisions, attention has begun to gain prominence and garner attention in the economics literature.

(II) **Inhibitory Control** is the ability to control impulses and minimize interference from irrelevant stimuli. For example, 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. This paper covers short-term memory, long-term memory, and working memory. Working memory is particularly useful in order to function well in society. It is the ability to evaluate new information as it enters, manipulate the information if necessary, and to delete or update irrelevant existing information. For example, a use of working memory is remembering a conversation with another conference attendee in order to revisit the topic later and perhaps incorporate parts of the comments to update an ongoing paper.

(IV) **Higher-Order Cognitive Functions** involve one or more of the basic cognitive functions and are perceived as more complex than the first three cognitive functions highlighted above. Cognitive flexibility is a higher-order ability that involves switching between tasks, rules, or mental sets (Lezak et al., 2004). For example, if starting tomorrow, your favorite crossword puzzle changes the rule to complete words diagonally instead of vertically and horizontally, the ability to adjust to this change could require a combination of inhibiting existing habits, attending to the old and new rules, and actively adopting the new rule—a more involved process compared to merely calling for one cognitive function. Cognitive flexibility could also be used inter-personally: to understand the perspective of others, and underpin the ability to complete tasks involving more complex skills such as problem solving and reasoning skills. Another example of higher-order cognitive function is intelligence. It is commonly separated into fluid and crystallized intelligence, where the first refers to the ability to solve novel problems and the latter involves learning new languages, new subjects, new words etc. They also involve some combination of core functions such as attention and long-term memory, rendering them "higher-order", more complex, cognitive functions.

These constructs, although broad, have the potential to help shape our understanding of the relationship between poverty, decision-making, and productivity. Each area 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 even potential for poverty traps. Before discussing the potential relationship between these areas of cognitive function and economic outcomes, we will begin by providing a more thorough description of each area of cognition, as well as ways of measuring them, in order to facilitate their integration into economic studies.

2.2 Definition and Description of Attention

Given its fundamental nature underlying many other functions and its relevance to many economic decisions, 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 attention's definition, role, and boundaries. In this paper, we aim to define attention in a manner consistent with the prevailing views in cognitive psychology, while still noting where some of the most substantial disagreements with that view occur.

At its most basic level, attention is the selection of information for further processing. People are faced with millions of stimuli every day but our brain filters out a large majority of them, enabling us to focus more effectively on the things we care about (Sternberg and Sternberg, 2011; Treisman, 2011; Cohen, 2014). In other words, attention is a matter of filtering information into or out of processing mechanisms. Given its 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 successful memory (Yates, 1966; Phelps, 2006).

Within the realm of attention, researchers have made significant headway in understanding the mechanisms behind 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 example, thinking about the upcoming deadline for a paper submission). External attention is the selection and modulation of incoming stimuli from your surroundings (e.g. watching the television screen).

- **Simple vs. complex attention.** Another classification draws a distinction between simple versus complex attention, as proposed by Lim and Dinges (2010a). Simple attention refers to attending to one stimulus while complex attention refers to attending to multiple stimuli at once. While this categorization is not very common among psychologists, measurement tasks that are devised to measure cognitive functions can be to a large extent related back to either simple or complex attention. As such, it 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 in considering downstream effects such as economic decision-making and productivity. For example, posterior and anterior attention studied in neuroscience focus on the specific neurotransmitters in the brain when attending to different stimuli and investigate in depth the particular brain cells at play (Peterson and Posner, 2012). These tests are usually conducted in laboratories using EEG (Electroencephalogram) and PET (Positron Emission Tomography) scans (Coull et al., 1996; Linden et al., 1996). 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.

2.3 Measuring Attention

One of the areas of attention with potentially severe 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 takes the form 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 the simple and complex forms.

2.3.1 Measuring Simple Attention: Psychomotor Vigilance Task

Within simple attention, one widely respected cognitive task for measuring attentional vigilance is the Psychomotor Vigilance Task (PVT), especially among sleep researchers (Basner and Dinges, 2011; Basner et al., 2011; Dinges et al., 1997). In this task, subjects are asked to press a button when a stimulus, for instance a light or a colored dot, appears. The task measures reaction time and accuracy—in other words, how quickly does the subject correctly press the button when the stimulus appears, and how often does he press the button when no stimulus appears (a false response)? In a review by Basner and Dinges (2011), the most common outcome metric of PVT was number of lapses, reported by 66.7% of published studies. Lapses is usually defined as a reaction time of longer than 500 milliseconds and understood as gaps 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 (with 40.4%, 30.5%, 29.8% and 28.4% frequency, respectively). PVT collects extremely granular data as it is administered on a computer (or other electronic device) and records time on the millisecond scale. Programmable factors such as inter-

stimulus interval, which is the time between the appearance of two stimuli, can be adjusted easily in the settings with exact precision. This task does not show learning effects nor is it affected by aptitude differences, making it appropriate for participants across a variety of settings (Lim and Dinges, 2008). The task does, however, require electronic administration, which can make it less convenient in certain field settings. To alter the difficulty of PVT, increasing the duration of the task generally increases mistake rates, especially when implemented along with a battery of other cognitive tasks (Lim et al., 2010).

2.3.2 Measuring Complex Attention: Concentration Endurance Test

In contrast to simple attention tasks, complex attention tasks include more than one stimulus and/or more than one rule. For example, the *Concentration Endurance Test*, also known as the "d2 Test of Attention", is a cancellation task aimed at measuring 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 participant's task is to identify and cross out only the letters d that have two associated marks. Common outcome variables include the total correct cancellations, the number of errors, and the distribution of errors. The task can be performed with shapes as opposed to letters for non-literate participants. The task can be made increasingly complex by adding more distracting letters surrounding the target stimuli. Notably, the task requires accurate visual scanning, which can be impeded not only by poor attention, but also poor eyesight, a common concern in developing countries. Similar to the *go/no-go task*, this task is sometimes considered an inhibitory control task (explained in Section 2.4 below). However, in contrast to the *go/no-go task*, the original test was developed for paper-and-pencil administration, and thus can be easily administered in field settings.

2.3.3 Sustained Attention Task

In *Sustained Attention Tasks*, participants are asked to focus on the screen as stars, rectangles, and circles on the screen shift around in the background, serving as distractions. Periodically, a triangle flashes at different locations on the screen. The participants' goal is to respond as quickly as possible to the triangle's appearance by pressing a pre-specified button. Frequently, outcome measures derived from reaction times are often measures of performance in attention tasks and can be used to signal gaps in attention (Sarter et al., 2001). This task is usually administered electronically. Importantly, the task does not rely on literacy as it uses simple shapes, making it suitable for rural field settings.

2.4 Definition and Description of Inhibitory Control

Inhibitory control is the top-down mental process used to block out a distraction, control an impulsive urge, and override pre-potent responses (Rothbart and Posner, 1985). It is sometimes

used interchangeably with self-control in the literature. Other times, it 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 well-studied in child development (Carlson and Moses, 2001; Diamond and Taylor, 1996; Mischel et al., 1989), and self control remains a prevalent concern among adults (Ward and Mann, 2000; Dempster, 1992). It is an important aspect of cognitive functioning that enables people to perform well socially, physically, at work, and in society. For example, discipline and self-control are required to refrain from eating the chocolate cake on the table when you are on a diet (Shiv and Fedorikhin, 1999), or to inhibit socially inappropriate responses when you are mentally drained (von Hippel and Gonsalkorale, 2005).

Although not typically considered in economics, self-control is called upon when faced with the tension between *endogenous attention* – selective, goal driven, voluntary, and top-down – and *exogenous attention* – impulsive, automatic, involuntary, and bottom-up (Diamond, 2013). The ability to exert self-control would be to inhibit the exogenous attention and activate the endogenous attention. As even the naming suggests, attention and inhibitory control are connected and very much inter-related, leading to debates in the field as to whether they rely on the same underlying construct (Rueda et al., 2005).

In addition to large individual differences in inhibition abilities, variable factors in the environment and in one's life circumstances such as tiredness 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 your impulses after exposure to stress (Glass et al., 1969) or working in a crowded space (Sherrod, 1974), both prevalent conditions among the urban poor. Empirically, recent prominent work on self-control have focused on exploring the consequences of depleted self-control and ways to overcome this depletion (Baumeister, 2002; Hofmann et al., 2007; Ariely and Wertenbroch, 2002; Hofmann et al., 2009).

The following section covers several cognitive tasks used by researchers to measure inhibitory control. The tests discussed have been applied to a wide range of settings and populations, providing a useful guide for designing future experimental studies related to inhibitory control.

2.5 Measuring Inhibitory Control

2.5.1 Hearts and Flowers Task

The *Hearts and Flowers Task*, previously known as the *Dots Task*, shows participants a screen which is divided into two panels and 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 on the same side of the screen as the heart whenever it appears. In the second round, they are then only shown flowers and are asked to click on the opposite side of the screen as the flowers. Finally, in the third round, individuals are shown both hearts or flowers, and the goal is to click on the appropriate

side according to the stimulus and the rule. This task requires both memory, to remember which symbol relates to which rule, and inhibitory control, when the participant is asked to click on the opposite side of the screen as the flower symbol. 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 are shown, or increasing the threshold for correct answers. Though this task is best administered electronically, it is well-suited for economic development research as it is quick, easy to explain, and does not require specific background knowledge or education level, making it applicable across a wide range of settings.

2.5.2 Go/No-Go Task

The *Go/No-Go Task* asks subjects to press a button whenever a target stimulus appears, but to withhold a response when other, competing stimuli appear (Jones et al., 2003; Cragg and Nation, 2008). Typically the"go" stimulus appears more often than the "no-go" stimulus, lending itself to be a "sustained attention" task because one becomes habituated by constantly responding to the "go" stimuli and finds it difficult to withhold their response when the occasional "no-go" stimulus appears. The no-go task could be considered as an unusual case of inhibitory control in the real world in that it does not require participants to inhibit one response to make another—it just asks them to inhibit one response (Aron, 2011). However, it is still applicable in a number of circumstances including when the evaluation of a situation suddenly changes just before taking an action—for instance, noticing a speeding car just as you are about to step off the curb and cross the street. Whether you are using the *go/no-go task* as a test of sustained complex attention or inhibitory control, accuracy and response time are measured as key outcome variables. This task does not require any background knowledge and is easy to explain, a strength across age groups and in settings with different educational backgrounds. However, it must be administered electronically, which might be a concern for some settings. Additionally, it is challenging to manipulate the difficulty level.

2.5.3 Eriksen Flanker Task

The *Eriksen Flanker task* shows participants 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). The target stimuli can be flanked by congruent stimuli (same response as the target stimulus), incongruent stimuli (opposite response to the target stimulus) or neutral stimuli. A common version of this task uses an arrow as the target stimulus, and respondents are asked to click in the direction the arrow points. Congruent stimuli in this task would have five arrows pointing the same direction, incongruent stimuli would have the flanking arrows pointing in the opposite of the target stimulus,

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

and neutral stimuli would be four unrelated stimuli flanking the target stimulus (for instance four boxes flanking a left-pointing arrow). Incongruent stimuli require participants to use top-down control to be able to focus on the middle stimulus (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. However, when conducted using arrows as described above, the test does not require any background or educational attainment level, and is a good test to separate inhibitory control from other cognitive functions such as working memory.

2.5.4 Stroop Test

The classic *Stroop test* displays a list of words spelling out 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 is 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 (e.g. blue in the congruent condition and green in the incongruent condition) (MacLeod, 1991). [2] Additionally, although a common test in developed countries, the Stroop test has a number of other negative qualities for development researchers. First among these is that it requires literacy and results are likely to be affected by different educational levels. A numeric version of the task can overcome the literacy barrier, although 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.

2.5.5 Spatial Stroop Test

The *spatial Stroop test* has the same basic concept as the classic Stroop task described above, but measures spatial rather than verbal and visual incompatibility. Participants are shown relevant and irrelevant dimensions of a stimulus which are similar and can influence responses. For example, 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. The Stroop effect appears as participants are generally slower when the arrow and side of the screen are incongruent as opposed to congruent (MacLeod, 1991). This task is particularly useful in separating working memory from inhibitory

[2] Although typically considered a prototypical test of inhibitory control, MacLeod et al. (2003) noted that the classic Stroop test, might not, in fact, measure inhibition. The authors note that the "Stroop effect"—the delayed response when color ink is different from 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 have occurred in the latter set of words.

control in that the direction of the arrow provides the participant with a natural "rule", using people's natural instinct to respond with the same side of the arrow. This limits the number of rules they need to hold in mind, which is a key feature of working memory. Furthermore, this task has an advantage over the classic Stroop task in that it does not require literacy if using the arrow stimuli. It is typically administered electronically, however, and there is little researchers can do to manipulate its difficulty.

2.6 Definition and Overview of Memory

2.6.1 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. In this space, information is said to reside for a short period of time and will be forgotten if not deliberately rehearsed or managed. The capacity of short-term memory is understood to be limited, and popularized by the well-known, 7 plus or minus 2, "magic number" for the number of items which can be held in short-term memory at the same time (Miller, 1956). Given extensive rehearsals and active processing, information solidifies and moves to be stored in long-term memory, where it is retained. When people's actions, decisions, and speech require them to retrieve information from long-term memory, it is moved back into short-term memory for active use. Compared with the limited capacity in the short-term store, the capacity of the long-term store is hypothesized to be unlimited (Cowan, 2008).

2.6.2 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, etc. This combination of temporary storage and manipulation is the core of working memory.

Figure 1 shows a simplified version of Baddeley-Hitch's model of working memory, which is composed of three main components: one higher-level component – the central executive – controlling two sub-components – phonological loop and visuospatial sketchpad – used to maintain different types of information. The phonological loop governs any verbal stimuli entering externally through speech or sound, whereas the visuospatial sketchpad governs the visual and spatial

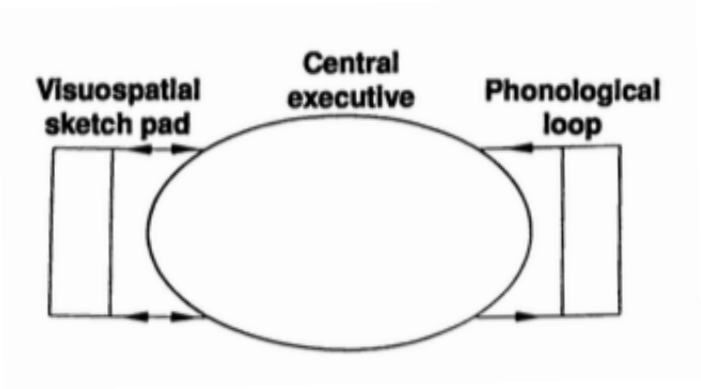


Figure 1: Simplified Version of Baddeley-Hitch's Working Memory Model

aspects of memory (Baddeley, 1986). The core governing component overseeing both of these sub-components is the central executive system. It is responsible for coordinating activities such as encoding, rehearsing, and retrieval of information(Gray, 1999).

There is some disagreement among psychological researchers 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 under working memory (Hasher and Zacks, 1998, 2006), which is popular within computational modeling (Miller and Cohen, 2001; Munakata et al., 2011). However, we have treated working memory and inhibitory control separately due to their different impacts on economic outcomes, as we will outline later in Section 4.

2.7 Measuring Memory

Cognitive psychologists have devised numerous cognitive tasks that tap into working memory ability. However, as the above discussion suggests, it is often difficult to fully tease out working memory from inhibitory control. This definitional disagreement also spills over to the design of cognitive tasks, where there are occasionally disagreements as to whether a specific task measures each cognitive domain. When such disagreements are common, they have been highlighted within the task description.

2.7.1 Measuring Short-Term Memory

I. Forward Digit Span Tasks. To measure short-term memory, researchers often use *Forward Digit Span Tasks* in which subjects are read a list of numbers and asked to repeat these numbers in the same order (Daneman and Carpenter, 1983, 1980). Subjects with lower numeracy may be at a disadvantage in this task, so simple items or words may be used in place of numbers as needed. This task is easily implementable in the field - it can be conducted without equipment, other

than what is needed to record participants' responses. Further, the task can be made more difficult simply by increasing the number of numbers or objects the participants are asked to remember.

II. Corsi Block Test. The *Corsi Block Test* is well suited to measure visual-spatial memory (Lezak, 1983). As part of this task, participants are shown a series of spatially separated blocks which individually change colors in a random sequence. Participants are then asked to 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 subjects are then asked to tap these blocks in the same order as the researcher did. The sequence typically starts out with a small number of blocks and is then made increasingly difficult by increasing the number of blocks in the series. As initially designed, the *Corsi Block Test* does not require mental manipulation, which makes it 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 subjects to reorder the indicated blocks (Feng et al., 2007). This task is also relatively easy to implement in the field, given that it can be administered on paper or electronically. The task also does not require any particular background (such as numeracy) making it particularly well-suited for development research. Further, its difficulty can be easily manipulated by increasing the number of blocks respondents have to remember.

2.7.2 Measuring Long-Term Memory

I. Benton Controlled Oral Word Association

The *Benton Controlled Oral Word Association* is arguably a measure of long-term memory by using vocabulary associations (Ruff et al., 1996). In the test, created in the English language, the experimenter provides the participant with a letter of the alphabet and instructs the participant to generate as many words as possible that begins with that letter. Words cannot be proper nouns such as people or places, and words cannot be repeated. Participants have one minute for each round, and the number of words generated is a measure of long-term memory (Benton, 1969). While this example is in English, vocabulary tests can be easily adaptable into other languages where the field experiment is conducted and could be made more difficult by adding constraints on the types of words allowed, e.g. only items inside a grocery store.

2.7.3 Measuring Working Memory

I. Digit and Reverse Digit Span Task. In this task, participants are asked to listen to a list of numbers and repeat them back in numerical (or reverse numerical) order. While this could be similar to the forward-digit span task described above, it is commonly used as a measure of working memory because it requires some manipulation of information instead of pure repetition. This task can be modified to have subjects listen to and repeat back non-numerical items and reor-

ganize them. However, these often also come with separate issues for development researchers, for instance, modifications might include providing subjects series of letters to list back in alphabetical order (requires literacy) or a series of objects to list back in order by size (requires background knowledge of items, which may differ across settings). This group of tasks is well-suited to measure verbal working memory.

II. Self-Ordered Pointing Task. This test can be used to measure non-spatial or spatial working memory (Petrides et al., 1993; Petrides and Milner, 1982). In this task, subjects 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 is touched. However, the locations of the objects are randomly scrambled in between turns. A modification of this task measuring spatial working memory has identical objects which remain stationary throughout the task (Diamond et al., 2007; Wiebe et al., 2010). It is possible to manipulate the difficulty of this task by increasing the number of items, and the task can be carried out in various field settings electronically or using physical objects (or paper drawings). Further, the task does not require a specific background or a certain level of education to administer it, making it appropriate across a range of settings.

2.8 Definition and Description of Higher-Order Executive Functions

The previous sections on attention, inhibitory control, and memory can be thought of as uni-dimensional executive functions because researchers attempting to understand the psychological domain typically focus on studying one specific aspect of functioning while controlling for or mitigating the influence of unrelated areas to obtain the cleanest results. However, as described previously, attention, inhibitory control, and memory are all interrelated and difficult to fully disentangle, potentially because they utilize the same region in the brain (Stuss and Alexander, 2000)[3].

In fact, actions we conduct and observe in real life rarely rely on only one cognitive domain and more often than not require a combination of these underlying functions. For example, think about the seemingly simple act of crossing the road, an "activity" that most of us do every day. All the core executive functions are at play here. First, you pay attention to the traffic light you are about to cross and the passing cars and buses 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 jaywalking if it 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 executive function,

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

our actions and decisions typically require a multi-dimensional approach, combining several of the cognitive functions that we have explained so far. In this section, we cover the more advanced types of executive functions, which we will refer to as "higher-order executive functions," focusing on cognitive flexibility and intelligence, two key areas of potential impact on economic outcomes.

2.8.1 Cognitive Flexibility

Cognitive flexibility refers to the ability to adapt to changing circumstances (Friedman et al., 2006; Andrewes, 2001). It is the mental process that is used when situation is altered and you need to adapt by updating the old rules to reflect the new circumstances, rules, or environment. Cognitive flexibility is hypothesized to be composed of three steps (Martin and Rubin, 1995; Martin and Anderson, 1998). The first is awareness that there are options and alternatives available in any given situation. The second is willingness to be flexible and adapt to a given situation. The third is choosing 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 being aware of it, and similarly, you would not successfully adapt to the new rule if you are not willing and able to change. To that end, cognitive flexibility is understood to be the opposite of rigidity (Diamond, 2013).

Cognitive flexibility is also referred to by other names such 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 names is the element of change and the ability to update previous beliefs and/or actions in response to changes in the environment (Monsell, 2003). For example, in a typical set-shifting task, participants are asked to conduct a task with a given rule. After some time performing the task, the experimenter informs the participant of a rule change. The participant will need to continue with the task following the new, changed rule and set aside the old rule. The experimenter may also ask the participant to revert back to the old rule after some time and proceed with the task to increase difficulty.

Several cognitive tasks have been created to measure this cognitive domain, with the most prominent one being the Wisconsin Card Sorting Task, which is explained below in Section 2.9.1. However, researchers have used the Wisconsin Card Sorting Task to measure other executive functions (not for cognitive flexibility) such as inhibitory control. While we have explained cognitive flexibility as a multi-dimensional function in this paper (as many researchers have), it is important to note that this description is not universally excepted and there are others who have argued that cognitive flexibility is a uni-dimensional function (Killgore, 2010; Miyaki et al., 2000).

2.8.2 Fluid and Crystallized Intelligence

General intelligence is widely described as having two components: fluid intelligence and crystallized intelligence (Horn and Cattell, 1967). *Fluid intelligence* refers to the ability to solve novel

problems and adapt to new situations. Frequently represented by variable *gF* in the literature, fluid intelligence is believed to be independent of acquired skills and knowledge (Cattell, 1963). Individuals using logic such as deductive reasoning to solve a puzzle or think about problems abstractly will be using fluid intelligence. As a higher-order executive function, it is most associated with memory, in particular, working memory, which involves updating and manipulating information (as described in section 2.6.2). In contrast, *crystallized intelligence* relies on the acquired skills and knowledge from one's schooling and/or upbringing. Crystallized intelligence is commonly abbreviated as *gC*. Examples of tasks used to measure crystalized intelligence include vocabulary tests or general knowledge and intelligence tests. Crystallized intelligence can be learned from experience or information and also relies on memory, in particular, long-term memory (Knox, 1997).

From the perspective of understanding overall cognitive functions, intelligence measures are also used interchangeably with other decision-making activities. For example, researchers have claimed that reasoning and problem solving are synonymous to fluid intelligence (Diamond, 2013), and others have discussed reasoning and crystallized intelligence together as a closely related construct (Lim and Dinges, 2010a).

2.9 Measuring Higher-order Executive Functions

This section covers tasks used to measure higher-order executive function. The tests are divided into three categories: (i) cognitive flexibility, (ii) fluid intelligence, and (iii) crystallized intelligence. While some are canonical and widely used, e.g. the Wisconsin Card Sorting Task and Raven's Matrices, others are general examples that we have included to serve as a guide and inspiration to illustrate the wide possibility of tasks that researchers could use or create to measure higher-order executive functions.

2.9.1 Measuring Cognitive Flexibility

I. Wisconsin Card Sorting Task. This task provides participants with a deck of cards, each of which can be sorted by color, shape, or number. Participants work to learn the correct sorting criterion based on feedback provided by the experimenter as to whether they have sorted the card correctly or not. However, the rules change periodically and without notification, such that participants must learn to change the sorting rule based on the feedback received. This task requires the ability to read and understand numbers, which could be a disadvantage in some settings. However, it is easy to explain and can be conducted electronically or with paper cards, making it practical in field settings.

II. Fluency Tasks. A group of tasks known as *Fluency Tasks* come in three main forms, however are all based on generating sets of related items. *Design Fluency Tasks* ask participants to list all the uses they can think of for a given item. For instance, participants are asked to list all the

uses they can think of for a table (Juliana V Baldo et al., 2001; Baldo and Shimamura, 1997). *Verbal Fluency Tasks* ask subjects to list all the words they can think of that begin with a single letter. *Categorical Fluency Tasks* ask subjects to alternate between listing objects from one category with objects from another category. These tasks both easy to explain and administer. They can be conducted verbally, on paper or electronically. However, different backgrounds, education levels, and aptitudes are likely to affect results and the verbal fluency tasks require literacy.

2.9.2 Measuring Fluid Intelligence and Crystallized Intelligence

I. Raven's Matrices Test. The most prominent and universally accepted measure of fluid intelligence and a common 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, subjects are asked to consider at a main figure which is missing a section. The task is to complete the missing section with 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 are centered on simple matching tasks such 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 contain around 60 such trials, more recent studies aiming to use this task as part of a larger battery of tasks contain 12 trials (Mani et al., 2013; Raven, 2000). The difficulty of Raven's Matrices task can be altered, for example, by increasing the number of multiple choice options that are available or the complexity of the rules needed to complete the puzzle.

II. Facial Recognition Test. This is a matching task which requires participants to identify unfamiliar faces after a brief exposure (Benton et al., 1994). In the first viewing, clothes and hair are shaded out of a picture so that the only features remaining are facial features. The participant is then asked to identify the target picture among six other three-quarter view photographs. Because the entire face is not shown, some reasoning skill is needed to complete the picture and identify the correct target. Alternatively, the participant may view the six options under different lighting conditions before being asked to select the one previously viewed. Both of these versions of the *Facial Recognition Test* do not rely on any language or prior knowledge, making it appropriate across a range of settings. However, poor vision will impede one's ability to complete the task successfully.

III. Wechsler Adult Intelligence Tests (WAIS). This test is frequently used as a measure of both fluid and crystalized intelligence. It is composed of 11 subtests, covering both verbal and "performance" components. The verbal sections include vocabulary, digit span, comprehension, and arithmetic. The performance sections include picture completion and arrangement, object assembly, etc. There are three scales of *Wechsler Intelligence Tests*: i) adult; ii) young children;

iii) older children, each with varying difficulty. As described above, tasks related to crystallized intelligence rely on previous knowledge. As a result, performance on subtests such as vocabulary or sentence completion could be limited by language skills, making implementation and interpretation difficult in many developing country settings. In particular, the test was designed for English-speaking countries, so many changes would be required to translate the task and to make it culturally and environmentally appropriate.

3 Impact of Poverty on Cognitive Function

Although it may seem odd that a person's fundamental "capacity" can be altered by their circumstances, there is a small but growing literature demonstrating that poverty can and does impact cognition in a variety of ways. Below we briefly discuss some of the factors associated with poverty which have been shown to impact cognitive function, as well as provide a non-exhaustive list of other aspects of life in poverty for which the evidence is more limited but suggestive of potential impacts, warranting further investigation.

3.1 Nutrition

One factor commonly associated with poverty is malnutrition - 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). Traditionally, economists have viewed 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 also affect mental function: thoughts may become lethargic, attention difficult to sustain, and temptations harder to resist.

Schofield (2014) tests this idea using an experiment to examine the impact of providing calories on measures of bandwidth among low-BMI cycle-rickshaw drivers in India over a period of 5 weeks. Participants completed 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 each day. In addition to improving labor market outcomes, individuals with higher caloric intake showed an almost immediate 12 percent improvement in performance on the cognitive tasks, a gain that was sustained at endline. These changes manifested not only in performance on laboratory based tests of cognitive function, but also in a real-world effort discounting task in which participants were given a choice to provide no labor and earn nothing, or take a journey with a lighter load today or a heavier load tomorrow, with both trips earning the same payment tomorrow. Treated participants were 25 percent more likely 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 professional activities.

3.2 Alcohol

Excessive alcohol consumption has long been associated with poverty (**?**), but its economic consequences are 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 bandwidth.

Schilbach (2015) conducted a three-week field experiment with the goal to show that such cognitive effects can translate into economically meaningful real-world consequences. In his study, reducing daytime drinking among low-income workers in Chennai via 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 just 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

Being poor means having less money to buy things, but it also means having to spend more of one's cognitive resources managing that what little money one has. The poor must manage sporadic income, juggle expenses, and constantly make difficult trade-offs between expenses. Even when the poor are not actually making financial decisions, these preoccupations can be distracting. Thinking and fretting about money can effectively tax mental resources.

Mani et al. (2013) use two distinct but complementary designs to establish the causal link between poverty and mental function. First, they experimentally induce participants to think about everyday financial demands. For the rich participants, this thoughts are inconsequential. For the poor, however, they can trigger persistent and distracting concerns, with corresponding negative impacts on cognitive performance. The second study uses quasi-experimental variation in actual wealth over time. Agricultural income is highly lumpy, 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 – poor before harvest and richer after – generating the opportunity to compare 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 you are poor, economic challenges are not just economic, they are also cognitive. Constant trade-offs and difficult decisions tax scarce cognitive resources even further.

Hoel et al. (2016) also find 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 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 exacerbated by heavy physical labor, uncomfortable living conditions, and limited access to adequate health care and pain management tools are limited (Poleshuck and Green, 2008; **?**).

A body of evidence demonstrates that pain may negatively impact 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, impacting 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, breaking into thought process at inopportune moments and potentially competing for limited cognitive resources (Eccleston and Crombez, 1999).

While little evidence exists about how these cognitive changes impact economic decisions to date, it is reasonable to hypothesize that pain may affect decision-making and labor market productivity. For example, Kuhnen and Knutson (2005) found that people make more suboptimal financial decisions and are more risk adverse after the anterior insula, the part of the brain that reacts to pain, is activated. While 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 and points to an area ripe for additional research.

3.5 Sleep Deprivation

While inadequate sleep is a widespread problem, the poor may, in particular not sleep well, especially in urban areas and developing countries. Individuals in these environments are likely to be at high risk of 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). Additionally, 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 impact of sleep deprivation increases with the cumulative extent of the deprivation, these impacts may be especially strong among those little few options for "catching up" given poor sleep environments (Van Dongen et al., 2003).

A robust body of evidence demonstrates that sleep deprivation and low quality sleep impairs cognition, including reducing attention and vigilance and impairing memory and logical reasoning (Lim and Dinges, 2010b; Philibert, 2005; Scott et al., 2006; Basner and Dinges, 2011). While the

body of evidence documenting the cognitive impacts of sleep deprivation is robust, much less has been done to document the impact of these cognitive changes on decision-making and productivity. Notable exceptions include a series of papers by Dickinson and co-authors which demonstrate that acute sleep deprivation (such as a full night without sleep) has mixed effects on risk preferences (Benjamin McKenna and Drummond, 2007), reduces trust and trustworthiness (Dickinson and McElroy, 2016), and reduces iterative reasoning in a p-beauty game in U.S. populations (Dickinson and McElroy, 2010). However, much remains to be done to fully understand the decision-making consequences of sleep deprivation, particularly in a developing country context.

3.6 Environmental Factors

Although evidence is more sparse, a variety of environmental factors including noise, heat, and air pollution may also tax cognitive function. These factors can 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 are prominent (World Bank, 2015).

In urban and developing environments, the frequent loud noise from cars honking, dogs barking, and crowds chattering could make it difficult to perform the task at hand. In lab and field settings, increases in noise may not only induce anxiety and affect mood, it may also impair performance on cognitive tasks, particularly those capturing attention and memory (Tzivian et al., 2015). There is also suggestive evidence that prolonged noise exposure may impact working memory and fluid intelligence (Chiovenda et al., 2007). Additionally, children are at an additionally increased risk of being impacted by constant noise exposure and show impairments in reading comprehension, attention, and memory (Stansfeld et al., 2005; Clark and Stansfeld, 2007). Despite these indications of impacts on cognition, there is limited evidence on the potential downstream impacts on decisions and productivity.

Heat also has the potential to impede cognitive function and impair motivation. This factor, and its potential impacts, are particularly relevant in developing countries, where the tropical environments and 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). Excessive exposure to 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 with high temperature has lower total agricultural output and economic growth, which could be explained by workers' reduced cognitive functioning (Dell et al., 2012). As global climate shifts occur, studying these causal impacts could become even more central, with the majority of the burden borne by developing countries.

In addition to heat stress, the use less energy-efficient technologies and lack strong enforcement mechanisms for pollution regulations has made high levels of air pollution common for many

individuals living in urban developing environments. Not only are pollutants harmful to physical health, there is also suggestive evidence that air pollution may be linked to cognitive impairments on domains including attention, processing speed, working memory and verbal memory (Tzivian et al., 2015). While few studies have mapped the entire causal chain from heat to economic decisions and outcomes, recent research are exploring the effects of oppressive heat on downstream effects such as reduced worker productivity, via a bandwidth channel in developing settings (Adhvaryu et al., 2014).

4 Cognitive Function and 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 sub-section, 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. It is important to emphasize that 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. Four primary strands of research modeling the role of attention in shaping economic behaviors have developed. We first briefly review each of these four approaches and and then discuss the existing empirical evidence in support of these models.

4.1.1 Theoretical Models of Attention

Rational Inattention. Consistent with evidence from cognitive psychology, 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 reduction in uncertainty and information cost is measured as an entropy-based penalty. This model has widespread applicability to many decisions. Among other topics, Sims' rational inattention model has been applied to price setting (Woodford, 2012; Maćkowiak and Wiederholl, 2009; Matějka, 2015), consumption 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).

However, to the best of our knowledge, 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 yet. Many other additional applications of this model also exist in a developing-country context. For example, the complexity of management of household finances among the poor requires the allocation of scarce attention across many competing sources, frequently including multiple income streams and obligations (e.g. loans).

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 his utility with his optimal action dependent on multiple variables. The agent uses a two-step algorithm to choose his 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. Gabaix expands this work to solve dynamic programming problems (Gabaix, 2016). Importantly, the idea of "sparsity" in Gabaix's context applies closely to limited attention, as well as to salience. For each decision a person is faced with, 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 can be seen in the "stickiness" of choices and overweighting of default options in organ donation rates (Johnson and Goldstein, 2003), retirement savings decisions (Madrian and Shea, 2001; Choi et al., 2006; Beshears et al., 2009) and insurance markets (Handel, 2013; Handel and Kolstad, 2015; Bhargava et al., 2015), even when the default or previously chosen option is strictly dominated by another option.[4] As above, although much of the research to date has occurred in developed contexts, there is broad applicability of this model to the study of poverty and development as well. For example, farmers must decide which aspects of the production process and potential input vector to attend to most closely.

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

(I) Bordalo et al. (2013) present a model of salience where an attribute of an option attracts more attention when this attribute is significantly different, or "stands out", relative to the

[4]While a form of inattention is likely to play a part in stickiness and the overweighting of defaults, other concerns are likely to play into "stickiness" as well, such as information availability and salience

average attributes in the individual's choice set. That is, *relative* differences in attributes (in terms of utility) influence salience.

(II) Kőszegi and Szeidl (2012) 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, Rabin, and Schwartzstein (2016) assume that the wider the range of utility for certain attributes, the *less* one attends to fixed utility differences.

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

Selective Attention. In a fourth strand of economics literature on inattention, Schwartzstein (2014) details how selective attention can have *persistent* effects on belief formation and learning. The idea behind Schwartzstein's model is that what an agent attends to today is dependent on their current beliefs. Following from this, what the agent attends to today will then also affect their beliefs in the future. In short, given incorrect initial beliefs, this attentional 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. Evidence supporting this theory can be found in a number of real-world settings. Historically, there was delayed recognition of the importance of sterilizing operating rooms to prevent infections, despite access to relevant data (Gawande, 2004; Nuland, 2004). Bloom et al. (2013) show that managers failed to adopt best practices in the Indian textile industry, despite natural variation that could point to the importance of attributes contributing to best practices.

4.1.2 Existing Empirical Evidence

Technology Adoption. Hanna et al. (2014) apply Schwartzstein's model to technology adoption in seaweed farming, demonstrating 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 use of technology often fail, and that it is essential that new users are attentive to certain features of the technology to use it properly.

Productivity. Attention has also been directly linked to poverty traps in existing theoretical work. 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 instad of remembering 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 has received more focus in the economics literature than many areas of cognition, there are still many unexplored ways in which constraints on attention may impact the lives of the poor. For example, workplace or traffic accidents or both substantial concerns among the poor, potential 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 put in place in more developed economies. For example, imagine a worker on a factory assembly line monotonously operating a machine, but his mind wanders off for a split second at the wrong time. In many resource poor settings, this lapse may result in a serious accident. While the same is possible in developed contexts, many precautions such as automatic shutdown mechanisms or safety equipment may prevent the same lapse from having such extreme consequences.

Similarly, consider the dire consequences of a driver losing focus on a highway after hours of commuting every day. In fact, 41% of car crashes in the US are estimated to be due to recognition errors, including inattention (USDT, 2008). Yet, these rates are likely to be significantly higher in developing countries where factors which 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 in place.

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

Each of these examples is just one of many potential pathways through which these effects may flow. Much work remains to be done to more fully 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, or the ability to regulate one's behavior when faced with impulses and temptations in order to follow through on an intended plan. Self-control problems have received enormous attention in the economics literature, including both theoretical and empirical work. Since several excellent reviews of this large body of work have been written recently (Frederick et al., 2002; DellaVigna, 2009), we review the theoretical literature in less detail than other sections.

4.2.1 Theoretical Models of Self-Control

(In progress.)

4.2.2 Existing Empirical Evidence

Lack of self-control and time-inconsistency can have important applications in both procrastination and addiction, topics of significant relevance in both developed and developing countries. People frequently face trading offs between immediate gratification and delayed benefits. For example, a person trying to lose weight (a delayed benefit) may plan to diet and exercise tomorrow, but when tomorrow comes, they do neither of these things and plan once again to start the following day. With addiction, a person might plan to only consume a moderate amount of an addictive substance, but after consuming that moderate amount, consume more then is desirable.

Borrowing, Saving, and Investing. A relatively large body of evidence suggests that self-control problems may interfere with low-income individuals' intertemporal choice. A number of studies show instances in which the poor fail to take up small and divisible high-return investment opportunities.[5] Moreover, the poor are more likely to borrow at high interest rates (Aleem, 1990; Karlan and Mullainathan, 2010).[6] 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.[7]

[5] 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.

[6] 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.

[7] Similarly, Shipton (1992) found demand for "lockbox" savings accounts in Gambia, and a number of studies on rotating savings and credit associations (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.

Consumption Choices. Apart from distortions in intertemporal choice, there is also evidence of self-control problems interfering 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) found 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 for sobriety.

Productivity. 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, as well as 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 other ways in which potential cognitive changes which alter self-control can impact the lives of the poor. For instance, 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 also require substantial self-control in order to regulate intake and maintain a healthy weight. Further, 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. However, among the poor, 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

Although indirect, a related literature examines the role of memory in the timing of actions. In economic life, individuals often need to decide whether to complete a task (e.g. paying a bill) in the present or future. If the task is left to the future, they may forget or an external factor may arise that would prevent them from completing the task.

4.3.1 Theoretical Models of 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, focusing on impacts on health and savings.

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 remembering 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 can affect how accessible a given memory is, and can thus be explanations for observed behavioral biases. Wilson (2014) presents a model of finite, bounded memory, which can explain a range of behavioral phenomena including salience, stickiness, confirmatory bias, over and underconfidence, and attitudinal or belief polarization.

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 and may lead people to "pre-crastinate" or incur a loss in the present rather than the future. Haushofer shows this empirically using tests conducted in Kenya, which confirm that people often pre-crastinate rather to waiting to act on future profitable opportunities whcih may be forgotten. 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 or uptake (Kremer et al., 2009).

Memory and Procrastination. Ericson (2016) notes that while reminders can have significant effects on actions, deadlines, which should force agents to overcome present bias and act, are often ignored even when such actions lead to substantial losses.[8] 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.

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

4.3.2 Empirical Evidence

A relatively large body of evidence has demonstrated the importance of memory by providing evidence that reminders can be effective at changing agents' behaviors.

Health. A large share of the evidence on reminders stems from the medical literature, in particular the literature on medical adherence. A relatively robust finding from this literature is that reminders typically have a modest but meaningful impact on health behaviors including smoking cessation, adherence to medication and treatment regimens, and preventive health behaviors such as sunscreen use (Karlan et al., 2016; Dulmen et al., 2007; Krishna et al., 2009).

Savings. Karlan et al. (2016) show that reminders can improve savings behavior, running an experiment with commitment savings customers in Bolivia, Peru, and the Philippines. The aThey 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 lack of savings and suggests that reminding people of long-term goals can be effective at changing behavior. Significant effects of reminders have also been found for loan repayments (Karlan et al., Forthcoming; 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.

But memory is central to economic outcomes beyond simply remembering to undertake tasks. In particular, working memory in particular 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. The decision to save money, for instance, requires giving up short-term enjoyent but often creates longer-term payoffs. As an example, increased savings behavior can allow a small business owner to invest and grow their business. Alternatively, lack of savings can may make it impossible for families to smooth consumption when there is an unexpected negative income shock.

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

[In progress.]

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, they are particularly relevant to the study of development and poverty because poverty may be both a cause and a consequence of such changes. We have traditionally considered a person's cognitive ability to be fixed, but in fact 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. This shift 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 relatively paucity of information generates an open and valuable areas of research to pursue: *how* do poverty and our 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. The mental bandwidth required to manage limited income, which is often lumpy and uncertain, can have significant effects on cognitive ability as shown in Mani et al. (2013). Schofield (2014) studies the impact of providing addition calories to low-BMI cycle-rickshaw drivers in India and finds that individuals who received additional calories perform better on tasks requiring mental stamina and show a substantial reduction in discount rates for effort in a real-world economic decision. Schilbach (2015) studies alcohol consumption, which has long been associated with poverty (Fisher, 2007), by randomizing financial incentives to reduce daytime drinking among low-income workers in India. He finds that these incentives increased daily savings

in a high-return account by 60 percent compared to a control group. Importantly, these additional savings were not due simply to increased earnings or decreased spending on alcohol. Yet, there are numerous other components and correlates of poverty whose effects on cognitive function are not yet well understood. For example, lack of sleep, chronic pain, noise or air pollution, and heat. Beyond these relationships, there are myraid other valuable directions of inquiry in this space to better understand these relationships, 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 components of poverty that we know can shift different executive functions will allow us to test predictions of the varied 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 consider how to develop our understanding of how cognitive functions are correlated 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 benefits such as useful information on potentail causes of cognitive deficits and substantial reductions in data collection requirements. There is some evidence that different tests of cognitive ability are highly correlated – literature has found that at least half of the variance between different cognitive tasks can be accounted for by a single general factor (Jensen, 1998; Lubinski, 2004; Spearman, 1927, 1904).

Cognition is likely to be an important contributor to poverty, while also having a strong potential to generate feedback effects, contributing to poverty traps. 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 much less about how exactly it influences 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 subjects responding to a stimulus.	No	No	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.	No	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	No	Electronic Only
Go/No-Go Task	A task that requires participants to perform an action when a certain stimulus appears, and inhibit that action when another stimulus appears.	No	Yes	Electronic Only
Stop-Signal Task	A task that requires participants to perform an action when a certain stimulus appears, but withhold response when a different "stop" signal appears.	No	Yes	Electronic Only
Eriksen Flanker Task	Subjects are shown stimuli and are asked to only respond to the central stimuli, ignoring flanking stimuli around it.	Sometimes literacy is needed	No	Electronic Only
Stroop Task*	A task in which subjects see the name of a color printed in a different ink color, and the subject is asked to name the ink color (e.g. the word "green" is written in red ink and the subject is expected to reply with "red").	Literacy required	No	Paper or electronic

Task Name	Description	Background Needed	Ability to Manipulate Difficulty	Modes of Administration
Spatial Stroop Task	Subjects are shown arrows and told to press in the direction the arrow is pointing. Arrows are shown on different sides of the screen and subjects 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	No	Electronic Only
Simon task	The subject is asked to press left for one stimulus and right for a second stimulus. The stimuli appear on both sides of the screen, one at a time. Subjects must overcome prepotent tendency to automatically press on the side that the stimulus appears if the locations of stimulus and the response are incongruent.	No	No	Electronic Only
Short-Term and Long-Term Memory				
Forward-Digit Span Task	Subjects are asked to listen to a list of numbers and repeat them back in the same order	Numeracy required	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.	No	Yes	Paper or electronic
Working Memory				
Backward-Digit Span Task	Subjects are asked to listen to a list of numbers and repeat them in numerical or reverse-numerical order.	Numeracy required	Yes	Verbal, paper, or electronic
Self-Ordered Pointing Task	Subjects 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.	Numeracy required	No	Paper or electronic
Design Fluency Tasks	Subjects are asked to think of as many uses as they can for an object such as a table.	Educational differences can affect outcomes	Yes	Verbal, paper, or electronic
Verbal Fluency Tasks	Subjects are asked to list all of the words they can think of that begin with a letter.	Literacy required, educational differences can affect outcomes	Yes	Verbal, paper, or electronic

Task Name	Description	Background Needed	Ability to Manipulate Difficulty	Modes of Administration
Categorical Fluency Tasks	Subjects are asked to alternate between listing objects from one category with objects from another category.	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
Facial Recognition Test	Subjects are shown a part of a face and have to identify the full face among a group, or subjects are shown a full face and have to identify the face among a group shown with different lighting.	No	Yes	Paper or electronic
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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