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Three Essays in Development Economics.

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UFR DE SCIENCES
ÉCONOMIQUES
ET DE GESTION

UNIVERSITÉ DE LYON - Université Lumière Lyon 2
Groupe d'Analyse et de Théorie Économique

Ecole Doctorale 486
Sciences Économiques et de Gestion

Three Essays in Development Economics

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Abstract

This thesis consists of the three following theoretical and/or empirical research articles:

- Risks and optimal migration duration: The role of higher order risk attitudes, *GATE working paper No. 2029* (2020).
- ‘Rural-urban migration as a risk coping strategy: The role of income differentials’ (2021).¹
- ‘Long-Term Effects of Environmental Policies on Educational Performance: Evidence from China’ (2022).²

From three different viewpoints, this dissertation explores the determinants and effects of two distinct human capital investment decisions. Each chapter is concerned with a particular topic and can, therefore, be treated separately. The two first chapters focus on the determinants of migration as a time disinvestment in child human capital. Chapter 1 explores how different types of risks affect decisions of optimal migration duration of parents with left-behind children. Chapter 2 explores the determinants of the parental migration decision when the later is used to diversify the household income against agricultural aggregate risks, and when children are to be left behind. Chapter 3 focuses on government interventions as investments in child human capital. Using an environmental policy implemented in some areas of China, it evaluates the consequences of exposure to this policy during the first year of birth on educational outcomes, 15 years later.

¹Based on a joint work with Sylvie Démurger and Béatrice Rey-Fournier.

²Based on a work co-written with Jie He (Sherbrooke university).

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General Introduction

Gary Becker's work on "human capital" marked a turning point in economic research. As stated by Becker himself in the third edition of his seminal book, the term "human capital" was not widely accepted by economists back then: "It may seem odd now, but I hesitated a while before deciding to call my book Human Capital-and even hedged the risk by using a long subtitle. In the early days, many people were criticizing this term and the underlying analysis because they believed it treated people like slaves or machines." (Becker, 2009).³ The motivation of this concept started with the findings that the growth of physical capital accounted only for a small part of the variation in economic growth. The importance of the other unexplained part led some scholars, mainly Schultz (e.g., Schultz, 1961), to suggest a new perspective to economic analysis where unmeasured skills and abilities of workers should be taken into consideration. However, it was Becker who constructed a theory about this unobserved factor, referred to as human capital, and defined as the set of knowledge, skills, health, or values embodied in a person, that may affect observed outcomes of people such as earnings and education. The role of human capital in explaining the gaps in productivity and inequality among countries has, therefore, been recognized (Becker, 1962, 1964), and ever since, human capital has been placed at the heart of economic analyzes and a substantial work on showing its importance for enhancing economic growth has been developed (e.g., Romer, 1986; Lucas, 1988).

At the individual level, both cognitive and non-cognitive skills have been shown to predict success in different aspects of social and economic life, including wages, schooling and criminality (e.g., Murnane et al., 1995; Heckman and Rubinstein, 2001; Bowles et al., 2001; Heckman et al., 2006; Borghans et al., 2008; Huggett et al., 2011; Kautz et al., 2014;

³Adam Smith argued, in the *Wealth of Nations*, that economic progress is related to the division of labor, but did not make a clear link between them (Smith, 1776; Becker et al., 1990).

Heckman et al., 2015, 2018). Moreover, a large part of the variation in the socioeconomic success across individuals can be explained by the differences in their abilities (Cunha and Heckman, 2007). These gaps that open up early in life play, therefore, important roles in creating inequality (Cunha and Heckman, 2009).

However, human capital involves abilities and skill sets that decision-making units are able to invest in, in order to improve their levels. Alfred Marshall stated, in the *Principles of Economics*, that “The most valuable of all capital is that invested in human beings” (Pujol, 1984), and that is true whether these investments are done at the micro- or macro-levels. In order to keep and increase a country’s competitiveness, physical capital investments are, therefore, not enough. Human capital investments are as important as, if not more important than, other types of investment (Heckman, 2003).⁴

Recent evidence on the effects of government human capital investments in developing countries, through educational and health policies, support this view. Increases in the number of years of schooling and wages have been documented following the increase in the number of schools in Indonesia (Duflo, 2001). Providing monetary support for secondary school students improved access of female winners to jobs with rents in Ghana (Duflo et al., 2021), while providing small cash transfers to fathers of school-aged children greatly increased school participation in poor rural areas of Morocco (Benhassine et al., 2015). Removing school fees in primary schools increased educational attainment for children in Tanzania (De Neve and Fink, 2018). Providing free learning-assistance for those lagging behind in basic literacy and numeracy skills has been found effective in increasing average test scores (Banerjee et al., 2007), while monitoring and offering financial incentives for teachers reduced their absence in school and increased children’s test scores in India (Duflo et al., 2012).

Government health policies are also important investments in people’s human capital. Public health spending, and particularly increasing medical care, improves test scores and reduces mortality rates of children (Bharadwaj et al., 2013; Farag et al., 2013). Combining social and health services also affects health outcomes. It was shown that a higher ratio of social to health spending improved the following health conditions: adult obesity,

⁴In addition to its important direct effect, investment in human capital may also have a long-term indirect effect on economic growth, and that is through its effects on investment in physical capital and technological changes (Acemoglu, 1998; Hanushek and Woessmann, 2015).

asthma, mentally unhealthy days, days with activity limitations, and mortality rates for lung cancer, acute myocardial infarction, and type 2 diabetes (Bradley et al., 2016). Positive effects of nutritional policies have also been documented. The introduction of iodine fortification has been found to increase wages in the United States (Adhvaryu et al., 2020), while nutritional supplementation for pregnant women enhanced weight gain for children between 0 and 3 in Senegal (Linnemayr and Alderman, 2011).⁵ Other policies that affect household resources are also important. Government policies affecting parental financial resources have positive effects on longevity (Aizer et al., 2016a), while policies promoting maternity leave led to more education and higher wages of exposed children (Carneiro et al., 2015). Child care national policies, replacing parental care, were also found to increase future earnings (Havnes and Mogstad, 2011).

Beyond the investment in the accumulation of human capital, “early life conditions” are also important determinants of human capital and it is, therefore, important to take them into account, including in public policy decisions. Different risk factors for children’s human capital deterioration, occurring as early as conception, have been documented, including, for example, diseases such as malaria (Venkataramani, 2012), maternal alcohol consumption (von Hinke Kessler Scholder et al., 2014), nutritional deprivation (Almond et al., 2015), maternal stress (Aizer et al., 2016b), family ruptures (Persson and Rossin-Slater, 2018), water pollution (Currie et al., 2013), and air pollution (Zhang et al., 2002; Black et al., 2013; Bharadwaj et al., 2017; Midouhas et al., 2018; Heissel et al., 2022). Zhang et al. (2002), for example, showed that air pollution is associated with respiratory problems for children, while Black et al. (2013), Bharadwaj et al. (2017), Heissel et al. (2022) and Midouhas et al. (2018) reported serious negative effects on their academic performance and cognitive abilities. Long-term outcomes, such as earnings, are also found to be associated with exposure to air pollution early in life (e.g., Isen et al., 2017).

Government remediation policies that aim to counter these risk factors are, therefore, of great importance for human capital formation. However, the timing of these policies’ implementation over the childhood also matters. Cunha and Heckman (2007) argued that, depending on early and late investments being complements or substitutes and on whether

⁵See Belli and Appaix (2003) for a review of the earlier studies on the effects of government investments in child health.

government investments are anticipated by parents, effects of national investments on the accumulation of human capital may differ. Early childhood government policies produce high returns for children from disadvantaged environments; however, later interventions for these children would not be as effective if perfect substitution is not what characterizes early and late investments, and the productivity of late investments is higher the higher the level of early investments (Cunha and Heckman, 2007). Empirically, evidence confirms the preeminence of early childhood interventions for the disadvantaged compared to remedial actions later in life (Cunha et al., 2010). Deworming programs in Kenya, for example, have been shown to improve educational outcomes and labor supply (Baird et al., 2016). Policies implemented to reduce blood lead levels are found to increase the probability to better perform in reading and math tests in Rhode Island (Aizer et al., 2018). Interventions including lead remediation services, education for caregivers, and nutritional and medical assessments, offered for lead-poisoned children, reduced antisocial behavior and improved school performance, in North Carolina (Billings and Schnepel, 2018).

On the other hand, the theoretical literature suggests that parents are the main contributors to the formation of their children's human capital through genetics, investments, and choices of child environment (Becker and Tomes, 1979; Cunha and Heckman, 2007). Monetary resources parents invest in their children, including investments in education, health care, the home environment and other goods and services, are indeed shown to be determinants of children's economic success, in terms of educational attainment, health, earnings and behavior (e.g., Yeung et al., 2002; Ho, 2019; Attanasio et al., 2020). Parental time investment is also as important. It is found to be positively associated with children's educational outcomes and cognitive skills (Fiorini and Keane, 2014; Thomsen, 2015; Bono et al., 2016; Gayle et al., 2018; Cordero-Coma and Esping-Andersen, 2018), to compensate initial birth-weight differences among siblings (Hsin, 2012), and to reduce gender gaps in reading and math scores in the early grades (Baker and Milligan, 2016). Many activities reflect decisions of time investments in children, including labor supply, divorce and migration. The latter can be thought of as a time disinvestment in the children's human capital, in the case where children are left behind, with migration duration measuring the level of this disinvestment. This is particularly common in developing countries, including

China (UNICEF, 2018), Sri Lanka (Pinto-Jayawardena et al., 2006) and the Philippines (Cortes, 2015).

In fact, economic conditions in developing countries are subject to frequent and unpredictable changes, making individuals and households, particularly those living around the subsistence level, vulnerable to different risks to their livelihood. Moreover, problems of moral hazard, information asymmetries, and difficulty to enforce contracts have implied a poor establishment of formal insurance and credit markets in those countries (Alderman and Paxson, 1994).⁶ As a result, different alternative informal risk-coping strategies have been used to counter the effects of income variation. Informal risk sharing, in terms of voluntary transfers and interpersonal loans, among long-lasting interpersonal networks, has been proven to be a major risk-coping strategy for rural residents (e.g., Ellsworth, 1989; Coate and Ravallion, 1993; Ligon et al., 2000; Foster and Rosenzweig, 2001). As theory suggests that efficient agreements to share risk with others have to be at the “community level”, most of the empirical tests are made at the village if not at a larger group level (Genicot and Ray, 2003). Even though full/perfect insurance is rejected, Townsend (1994) found evidence consistent with substantial insurance at the village level, in southern India. Similar results are reported by Udry (1994) in northern Nigeria, by Jalan and Ravallion (1999) in rural China, and by Kinnan (2022) in Thai villages. There is also evidence that some households engage in risk-sharing arrangements within the same ethnic group in Cote d’Ivoire (Grimard, 1997), and within caste risk-sharing groups in rural India (Mazzocco and Saini, 2012), while Fafchamps and Lund (2003), for example, found that risk-sharing networks are build among friends and relatives rather than at the village level, in rural Philippines. However, a limitation of this informal insurance mechanism is its ineffectiveness in managing spatially covariant risks, common at the regional level.⁷ It was shown, for example, that informal risk-sharing was reduced between households during the Covid-19 pandemic in Kenya (Janssens et al., 2021).

Other than risk-sharing networks, the theory suggests that savings are used as a self-insuring strategy to deal with risk (Leland, 1978; Kimball et al., 1990; Baiardi et al.,

⁶The absence or the ineffectiveness of formal insurance and credit markets may be one the factors for the persistent levels of poverty in developing countries (Morduch, 2006)

⁷The empirical literature typically distinguishes idiosyncratic risks and aggregate risks, where the former affects only one decision-making unit (the individual or the household) while the latter affects simultaneously a large number of decision-making units in a particular region.

2020). Several empirical studies have reported evidence that higher levels of risk are indeed compensated by higher levels of savings in different contexts including, for example, rural Bangladesh (Adnan et al., 2018), rural Pakistan (Lee and Sawada, 2010; Ullah et al., 2015), and both rural and urban China (Jalan and Ravallion, 2001; Meng, 2003; Giles and Yoo, 2007). These precautionary savings cover the accumulation of a wide range of assets, such as liquid, semi-liquid and fixed assets in the form of cash, farming tools, crop inventories and livestock (e.g., Rosenzweig and Wolpin, 1993; Alderman, 1996; Fafchamps et al., 1998; Park, 2006). Park (2006) argued, for example, that grain stocks are an attractive form of precautionary saving for Chinese households, even in the presence of credit opportunities. Precautionary saving is, however, costly for savers as it may prevent productive investments. It may also become ineffective in the presence of frequent realizations of risks. In fact, evidence shows that households reduce their precautionary saving in the presence of migration opportunities in the form of larger migrant networks (Giles and Yoo, 2007).

In India, for example, Rosenzweig and Stark (1989) showed the effectiveness of marital migration by women as a way to extend insurance network into far-away areas, in an attempt to create a source of monetary help that is uncorrelated with local earnings. Indeed, according to the New Economics of Labor Migration, households may allocate some of their labor supply to migration markets, in case of ineffective informal strategies or if they want to preserve their savings and other assets, as a way to diversify their local income (Stark and Levhari, 1982; Stark and Bloom, 1985).⁸⁹ This theory is, therefore,

⁸In the case of migration, decisions may be characterized as being associated with both risk and uncertainty, even though the focus has been on risk rather than on uncertainty both in economic theories (Williams and Baláz, 2012) and in empirical applications, as risk has the property of being measurable. In different empirical contexts, both aggregate and idiosyncratic measures of risk have been used, including, variability of GDP (e.g., Joon-Ho, 1999; Menegatti, 2010; Mody et al., 2012), employment probabilities (e.g., Barnum et al., 1977), unemployment rates (e.g., Mayda, 2010; Mody et al., 2012; Bande and Riveiro, 2013), variability of weather variables (Rosenzweig and Stark, 1989; Dillon et al., 2011), and standard deviation or variance of income or income equation residuals (e.g., Carroll and Samwick, 1998; Jalan and Ravallion, 2001; Mishra et al., 2013). The above are objective measures of income risk, but subjective measures can also be used. The later can be constructed, for example, using survey questions on the probability distribution of earnings and inflation (Guiso et al., 1992; Lusardi, 1997), or on unemployment expectations (Carroll and Dunn, 1997). Risk differs from uncertainty in the sense that the probabilities of the different outcomes of a given event are known, while uncertainty refers to situations where information about the likelihood of possible outcomes is not available (Tobler and Weber, 2014).

⁹We distinguish between risk and the realized risk, known as shock. These two are different in the sense that, in the case of a negative shock, decision makers will try to minimize the already underwent adverse effects, while in the case of a risk, they will try to adjust their behavior to account for the possibility that

suggesting that, contrarily to what is stated in the human capital models of migration, migration of individuals to destinations with lower incomes or higher risks is possible as long as it helps the household to reduce its overall riskiness.¹⁰ As migrants move with the purpose of insuring their households against risks, most of them may be migrating only temporarily and hence would not be relocating their entire family to the destination location. This is not an unusual behavior of migrant workers in real world markets, even in the presence of higher earnings in the destination areas (Banerjee and Duflo, 2007).

In addition to the above-cited insurance motive, the theoretical migration literature has offered multiple incentives for why migration would not be permanent, hence probably resulting in left-behind children. Early studies mostly referred to preference for consumption in the home country as the motive for temporary migration (e.g., Hill, 1987; Djajić and Milbourne, 1988). As the marginal utility of consumption is higher in the country of origin, compared to that in the destination country, migrants save and accumulate assets while abroad and de-save after their return, providing themselves with a higher consumption. A similar motive concerns the higher purchasing power of the destination country's currency in the country of origin, in terms of lower price levels. In this scenario, migration will never be permanent in the absence of earnings differences between the two countries, as the incentive of migration comes only from the destination country's currency's purchasing power in the home country (e.g., Dustmann, 1995, 2003). Skills, accumulated in the destination country, increasing migrants' human capital and having higher returns in the country of origin may also induce a temporary migration (Dustmann, 1995), including when self-employment activities allow a higher return when established in the home coun-

a negative shock may occur in the future. Most of the migration and child human capital investment literature focused on studying the effects of shocks, rather than risks. Examples of these shocks include those induced by adverse weather conditions and other events of nature such as typhoons (e.g., Jensen, 2000; Yang and Choi, 2007; Aguilar and Vicarelli, 2011; Gröger and Zylberberg, 2016; Minale, 2018), and nutritional shocks such as famine (Almond et al., 2010). In this case, endogeneity is rarely a problem for causal inference as shocks usually occur beyond human control.

¹⁰Human capital theory has long considered migration as an investment in one's human capital, in the sense that income is a return to this investment. This view of migration was first stated by Sjaastad (1962): the migrant considers the opportunity values of each possible destination relative to that at the area of origin, while also accounting for migration costs, and chooses the location that maximizes the lifetime earnings. Becker (2002) directly calls migration a human capital investment by stating that "Most investments in human capital—such as formal education, on-the-job training, or migration—[...]". The micro-economic version of the neoclassical theory of migration is based on this simple framework, to which Todaro (1969) and Harris and Todaro (1970) added the assumption that prospective migrants consider expected income at the destination area, instead of the actual income.

try (Dustmann and Kirchkamp, 2002). In fact, in the presence of borrowing constraints, self-employment may even motivate the decision to migrate with the aim of accumulating the initial required capital, and hence the return decision (e.g., Mesnard, 2004).

However, migration as a risk-coping strategy is also imperfect, as it may be costly or itself risky (Bryan et al., 2014). The theoretical migration literature proposed that the insurance contract between the household and the migrant can be reciprocal, since the migrant may also face different risks in the destination area (Stark and Lucas, 1988). The unemployment risk, which was introduced into the migration-decision models by Todaro (1969) and Harris and Todaro (1970), is one of the important examples of risks for migrants, as they may fail to find a job upon their arrival in the destination country (Das et al., 2019). This migration riskiness may even decrease the probability to migrate in the first place (Bryan et al., 2014).

The present work aims at analyzing two types of investments in the human capital of children, in the presence of a risky context: migration and environmental policies.

A large part of the literature has documented the different informal coping strategies used by rural households when faced with income riskiness, including migration. However, little has been done to understand the mechanisms driving the use of migration by households to diversify their income when faced with an aggregate income risk, particularly when parents have to migrate while children are to be left behind. Moreover, a high number of factors affecting the migration duration decision have been examined in the theoretical and empirical migration literature, but far less has been done on how monetary and child human capital riskiness determines the migration duration of parents. Chapter 1 models migration as a parental decision of time disinvestment in child human capital, with the aim of increasing future accumulated wealth. It explores the effects of different (*idiosyncratic* or *aggregate*) risks, as defined by the *stochastic dominance* theory (e.g., Eeckhoudt and Schlesinger, 2006), on the migration duration of parents with left-behind children. Chapter 2 examines income differential as a potential mechanism through which *aggregate* income risk affects the decision to send a parent for migration by a household that cares about both its income and children's human capital.

On the other hand, environmental policies, implemented early in children's life, can be considered as government investments in child human capital. While a lot has been said on

the effects of air-pollution, particularly using short-run analyzes, in developing countries, little has been done on the long-term effects of early-life government interventions when children's human capital is at risk of deterioration because of air pollution. Environmental policies affect human capital through many channels other than changes in air quality. Chapter 3 investigates the long-term effects of exposure to an environmental policy, in the first year of birth, on educational outcomes, as a way to empirically assess the importance of early-life conditions, particularly those that can be affected by policy makers.

The contribution of this thesis is in part theoretical but essentially empirical. While when theorizing decision-making of individuals or households under risk, Expected Utility Theory (EUT) framework is adopted, empirical illustrations are based on data from China. The choice of China is mainly driven by suitability for the research questions.

Case study: China

Since the open-up strategy and the economic reforms implemented in the late 1970s, China has witnessed an accelerated development of its economy. Ever since, its real GDP per capita has grown by about 9 percent, on average, each year (Li et al., 2017), and during the years between 2000 and 2007, China accounted for about 35 percent of the world's GDP growth at purchasing power parity prices (Ding and Knight, 2011). An important factor for China's growth success is due to its substantial physical capital investments, reaching a level of about 30% of its GDP in 1995 and more than 45% in 2002 (Heckman, 2005). Between 1979 and 2008, the total amount of foreign direct investment (FDI) reached US\$1,096.6 billion, making the FDI per capita higher than that in South Korea at the same stage of economic development (Heckman and Yi, 2012).

This increase in physical capital investments led to an increasing demand for workers. However, starting from the mid-1990s, the one child policy, adopted in China in 1979, was responsible for the decrease in the urban-born labor force, raising the need for migrant workers. The relaxation of the rural-urban migration restrictions was, therefore, an important factor for the continuing growth of the urban economy.¹¹ The new jobs created in

¹¹What makes rural labor migration to China's cities a unique process is its household registration system, implemented in the 1950s and maintained to this day. This system requires that every person born in China is classified according to two criteria, the type of *hukou* (urban (non-agricultural) or rural (agricultural)) and the location of *hukou*. It therefore allows the government to strictly regulate population flows, particularly between rural and urban areas, and to limit access of each citizen, to

industrial and service sectors were, therefore, mostly filled with migrant workers from the agricultural sector (Ding and Knight, 2011). This led to what has been called the largest labor migration in human history in recent decades. In 1990, the total "floating population" stock was only about 29 million, but reached 68 million in 1996 (Liang, 2001).¹² The momentum continued throughout the late 1990s to reach 121 million in 2000, then 221 million in 2010 and 247 million in 2015 (NBS, 2019).¹³

Migration, not only allowed rural residents to earn higher incomes (Zhu, 2002), but it was also a way for households to deal with negative agricultural shocks (Giles, 2006; Minale, 2018). Remittances are also found to particularly increase when families experience these income shocks (Du et al., 2005). The effect of risk on the decision to migrate is, however, less established. Jalan and Ravallion (2001) found that a higher household income risk reduced out-migration for work.¹⁴

Internal labor migration in China is mainly temporary and circular (Hu et al., 2011). It is an important source of income for the remaining households in the place of origin, but often leads to the separation of families. In 2015, for example, an estimated 69 million children were left behind by one or both migrant parents, representing about a third of all rural children in China (UNICEF, 2018). Due to the separation following parental migration, adverse effects may arise for children left behind. Profoundly disturbing conse-

essential public services, in only their local administrative unit of residence (Song, 2014; Zhou et al., 2021). With the growth of China's economy and the parallel increase in demand for rural labor in cities, the *hukou* system has undergone various relaxations during the 1990's and 2000's. The 10th Five-Year Plan, which covers the period from 2001 to 2005, briefly suggests canceling unreasonable restrictions for rural residents to migrate and work in cities, while the 11th Five-Year Plan, concerning the period from 2006 to 2010, gives more details on how local *hukou* should be granted to migrants with stable jobs and houses in the destination area, and explicitly reports how rural migration should be encouraged towards small and medium sized cities and small towns (Hsu and Ma, 2021). However, despite the various reforms, the majority of rural migrants in cities have not had the possibility to change their original status (Song, 2014).

¹²The most consistent measure of migration and the more readily available in China is the "floating population" size. It includes those who have an urban or rural *hukou*, but who have lived and worked in a place different from where they have their household registration status.

¹³Different definitions of temporary migrants have been used. A temporary migrant is anyone who has stayed in their place of destination for at least one year for the years 1982 and 1990, and for at least 6 months for the year 1996 (Liang, 2001). According to NBS (2019), a migrant is anyone who has resided in a place other than their area of registration for more than six months, excluding those whose resident and registered streets or towns are different but still within the same municipality or prefecture.

¹⁴Among the other risk-coping strategies for Chinese rural households figures the precautionary saving. Giles and Yoo (2007), for example, found that, facing a median level of consumption risk, almost 10% of household savings can be attributed to a precautionary motive, and this increases to 15% for households whose per capita consumption is below the poverty line.

quences have been documented for their educational outcomes. Compared to their peers with no migrant parents, they were found to be worse off in terms of school enrollment and years of schooling (Lee, 2011; Wang, 2014). Parents' migration is also found to negatively affect school performance and cognitive skills of left-behind children (e.g., Zhang et al., 2014; Zhao et al., 2014; Hu et al., 2020; Mao et al., 2020), as well as increasing the risk of unhealthy behaviors (Gao et al., 2010; Wen and Lin, 2012), and resulting in poorer mental health outcomes (Qin and Albin, 2010). These adverse effects are found to be stronger when both parents migrate. Moreover, Meng and Yamauchi (2017) argued that focusing on the effects of contemporaneous parental migration may be an underestimation of the true effects. They showed that the cumulative parental migration, over the childhood, have sizable adverse effects on children's health and education outcomes, while Zhou et al. (2014) reported that children with longer parental migration durations had poorer educational performances.

Long-term effects of exposure to parental migration, early in life, on labor market outcomes have also been investigated. Wang et al. (2021) showed that exposure to a left-behind experience, following the mother's migration, had adverse effects on the probability to find a job and wages. The long-term negative effect on incomes was further confirmed by Feng et al. (2022). Zheng et al. (2022) also reported damaging effects of early-life exposure to left-behind experience on cognitive abilities, in terms of fewer schooling years and lower cognitive test scores, and on health, in terms of chronic diseases and depression. They also tend to have poorer household socioeconomic outcomes, compared to their non-left-behind counterparts. These negative effects may even be transferred over generations, as the offspring of left-behind children are found to be adversely affected, in terms of birth weight and height-for-age z-scores (Zheng et al., 2022). These effects can be absolutely explained by the reduced time investment in children by the migrant parents. This time disinvestment may affect children's outcomes in different ways, including through the adverse effects parental absence may have on the physical and mental health of left-behind caregivers, including grandparents and spouses (Chen et al., 2015; Xiang et al., 2016; Tong et al., 2019). Parental migration may also reduce parents' recognition of children's education, and thus may reduce educational investment in left-behind children (Lu and Pang, 2022). The absence of parents may also affect the way left-behind children

allocate their time to activities beneficial to the formation of their human capital, with evidence showing that they increase their time spent on farm work and domestic work (Chang et al., 2011).

Despite these negative effects, rural-urban migration continued in China, as the economic growth continued. However, throughout the years, the demand for high-skilled workers increased and the return to education as well.¹⁵ If the country's economic success was initiated by a combination of medium-skilled workers and high levels of FDI inflows, it has been sustained by both physical capital and human capital investments (Heckman and Yi, 2012).¹⁶ The government has, indeed, made substantial investments in improving its labor's quality.¹⁷ Hongyi and Huang (2009), using provincial data, showed that both education and health have had positive effects on economic growth in China. Public spending on education, for example, was limited to 2.4% of its gross domestic product (GDP) in 1995, but increased to reach 3.3% of its GDP in 2002 (Heckman, 2005), and 4% in 2012 (Su and Liu, 2016). Government investments in education were not only important for the overall growth of the economy, but also for each individual's economic well-being. Xiao et al. (2017) found positive long-term effects on math test scores and the completed years of schooling, from providing free education by the government during the nine compulsory years of schooling, in rural China, starting from 2006.¹⁸ In the short-term, the reform was also found to stimulate enrollment in primary and junior high schools (Chyi and Zhou, 2014; Shi, 2016). Education was further shown to be an important factor for increasing incomes of rural workers (Knight and Song, 2005).

Moreover, China has also implemented different health policies, with the aim to improve people's human capital. Access to on-premise tap water was provided to only 11% of rural households in China, but thanks to its rural drinking water program, initiated in the 1980s, the share of rural households having access to on-premise tap water reached 55% by 2015 (WHO and UNICEF, 2015). Chen et al. (2020) examined the long-term

¹⁵High-skill workers refer to those with tertiary education.

¹⁶Primary or secondary education graduates are referred to as medium-skilled workers.

¹⁷For China's future economic success, Li et al. (2017) argued that the government should increase investments in human capital and put less emphasis on physical capital investments, as the former would have a higher impact on the country's future growth.

¹⁸The Chinese government has implemented different educational reforms to reduce education costs in 2001, 2003 and 2006. After the 2006 reform, all rural students were exempt from paying tuition while eligible ones were offered free textbooks and living subsidies.

effects of exposure to tap water during early childhood, and found positive effects on cognitive test scores at ages 10-15. In the short-term, access to treated water in rural China was found to improve children's weight-for-height and height outcomes (Zhang, 2012), and their completed grades of education (Zhang and Xu, 2016).

However, in addition to these education and health investments, government remediation policies, that aim to counter risk factors for people's human capital deterioration, were also documented. One example of these risk factors that has drawn much attention, in recent decades, is pollution. In fact, China's rapid economic growth has had severe repercussions for the environment, raising air pollution to levels harmful to human capital (Zeng et al., 2019). There is evidence that different air pollutants have caused serious damage for both children's and adults' outcomes in China, including their health (e.g., Zhang et al., 2002; Deng et al., 2015; Deschenes et al., 2020), education and cognitive functioning (e.g., Tang et al., 2008; Zhang et al., 2018a), their work productivity (e.g., Chang et al., 2019; He et al., 2019), labor supply (e.g., Zhang et al., 2018b), migration (e.g., Lu et al., 2018; Qin and Zhu, 2018) and well-being (e.g. Zhang et al., 2017; Smyth et al., 2008). It was also shown that air quality degradation in China is inhibiting economic and social growth and sustainable development (Li and Zhang, 2019; Liang and Yang, 2019; Zeng et al., 2019). The Chinese government has, therefore, invested huge resources in restoring and protecting its people's human capital from the impacts of air pollution, among which figures the Two Control Zones policy, implemented in 1998.

Overview of the chapters

Human capital is an important input for the social and economic success of a country as a whole and for each of the individuals. The present work proposes to study fundamental decisions that affect the human capital accumulation of individuals, namely household decision to migrate and migration duration, and government environmental interventions. Migration, being a disinvestment in the child human capital, is, in this dissertation, alternatively a way to accumulate wealth in the future by individuals, and a risk-coping strategy to diversify income by households. Environmental policies are, however, large scale government tools to affect individuals' outcomes.

Chapter 1 ‘Risks and optimal migration duration: The role of higher order risk attitudes’

In a world where many migrations are temporary, the stock of migrants at any destination country is, in part, determined by migration duration. What determines the optimal migration duration is, therefore, of immediate economic interest for both the home and the destination countries. Migration has long been theorized as affected by and affecting risks. The latter may be encountered in various forms, hence the importance to understand their impact on migration duration. Chapter 1 focuses on the temporary migration of parents with left-behind children, and considers migration duration a time disinvestment in child human capital. Parents are faced with a resource transfer problem, in the sense that, by migrating, they choose to sacrifice an amount of their children’s human capital in order to increase their accumulated wealth once back in the country of origin. Do risks affect the migration duration of these parents? Do all risk-averse migrant parents decrease their migration duration in the face of an income risk in the destination country, and increase it in the face of an income risk in the country of origin? How do they react to a risk on the human capital of their children or to a risk on their accumulated savings? Answers to these questions are important for both the sending and the receiving countries, because the expected duration of migration can affect migrants’ different economic choices, including consumption, saving, remittances, labor-market participation, leisure, human and social capital investments (e.g., language skills and networking) and ensuing assimilation profiles. While a handful of papers have examined the effects of income shocks, so far no paper, to our knowledge, has empirically explored how risks may affect migration spells, despite the relevance of risk in different circumstances. At the origin of this gap may lie the scarcity of theoretical references for the mechanisms underlying these effects and the suitable measures of the different risks. Bodvarsson and Berg (2013) argued that theoretical work in the migration literature is still very limited and that a huge gap between theory and empirical work is in place. They showed the need for more theoretical work that would serve as a guide for future research.

Chapter 1 provides a theoretical framework for modeling temporary migration decisions of parents with left-behind children, and shows that migrant parents do not necessarily change their migration duration, when faced with a change in risks, even if they are

averse to risk. First, analogously to including a dummy variable for the presence of risk in empirical studies, I focus on examining how the parents' migration duration changes when faced with pure risks or zero-mean speculative risks on income, child human capital or accumulated savings, compared to a situation with no risks. I show that not all risk-averse migrant parents react to these risks. Conditions on their other risk preferences are required for a change in the return plans, and depending on the nature of these preferences, the direction of the change, being either an increase or a decrease of their stay abroad, is determined. Second, I explore changes in risk that increase variance or moments of higher order of incomes, children's human capital or that of the accumulated savings. In a way similar to the previous case, I provide sufficient conditions on preferences ensuring a change in their migration behavior, and explaining the heterogeneity in the parents' optimal responses to changes in risks. Finally, in the absence of riskiness, I show that larger income differentials between the destination and home countries do not unavoidably increase the migration duration. They may lead to longer migration cycles only if an extra unit of child human capital becomes less valuable for parents following the increase in their income (i.e., income and child human capital are substitutes). The feature of parents' preferences that measure this behavior is referred to as correlation aversion. The parents' correlation attitude is also shown to affect migration duration decisions under risk of the parents.

Chapter 2 'Rural-urban migration as a risk coping strategy: The role of income differentials'

Climate change is becoming a serious problem for different economic agents, particularly agricultural households, by increasing income risks for them, through rises in rainfall variance and temperature fluctuations, for example. Rural households in developing countries are particularly vulnerable to these effects of the climate change, in view of the absence or the ineffectiveness of formal insurance and credit markets. While there exists widespread evidence on the use of migration as a risk-coping strategy by these households, little is known about the mechanisms that are affecting the use of this particular strategy, when risk-sharing arrangements may become ineffective. This question is particularly stringent for the debate over the welfare and poverty of agricultural households,

as well as the labor allocation between local and migrant markets. Two possible reasons for this literature gap are on the one hand, the difficulty to access databases with income and migration information at the household level, and the other hand, the focus of the migration theory on the different determinants of the migration decision separately while disregarding potential interactions between them. In a risky context, migration is seen as an important risk-coping strategy even in the absence of income differentials. Empirical work, however, shows that, sometimes, risk inhibits migration from rural areas. To date, nothing is known about the way the income differentials affect the migration decision in the presence of an aggregate income risk. To study this issue, Chapter 2 builds a model of an agricultural household, with at least one child, where the parent may migrate as a way to diversify income against riskiness. Using data from rural China and applying a Heckman and Lee procedure to compute the expected income differentials, we estimate assumptions of the theoretical model. We find that a negative expected urban-to-rural income difference, in the case of an aggregate income risk, decreases the probability of migration as a risk coping strategy, compared to a situation where the expected income differential is positive. We also show that this effect diminishes with higher levels of income differential. Moreover, as we focus on the migration of parents, the household's welfare depends not only on their income but also on their children's human capital. Our model shows evidence that the marginal utility of the household income increases as the child human capital deteriorates, suggesting that the considered Chinese rural households are correlation averse, i.e., in the case of an agricultural income risk, each additional monetary unit is more desirable for the household when children have lower school test scores. This result suggests that, in a migration context, if income differential is positive and the household is faced with an income risk, parents with children poorly performing at school may be more likely to migrate, compared to parents with better performing children.

Chapter 3 'Long-Term Effects of Environmental Policies on Educational Performance: Evidence from China'

Chapter 3 is concerned with the importance of early-life conditions, particularly those that can be controlled by policy-makers, in determining long-term human capital outcomes. While short-term effects of air pollution in developing countries have been widely

documented, little is known about whether exposure to the implementation of an environmental policy, early in life, affects long-term adult outcomes, and if it does, in which direction. Two main reasons may explain this gap. First, environmental regulations in developing countries are scarce and when found, they are either not sufficiently enforced or do not allow a suitable empirical analysis. Second, an important difficulty in exploring the effects of fetal and early-childhood conditions on adult outcomes is the long time it may take to be able to do so. The “Two control zones” (TCZ) policy, implemented in China in 1998, offers a perfect case study to examine the effects of exposure to an environmental policy early in life, as it has been stringently enforced only in particular areas of the country. To overcome the second difficulty of getting data on long-term adult outcomes, impacts on outcomes from younger ages are explored, while showing how predictive are the latter of longer-term outcomes. Using data from rural and urban China and applying a difference-in-differences approach, we find positive and significant effects of exposure to the TCZ policy, in one’s year of birth, on children’s long-term educational outcomes, 15 years later. Particularly, we find that, in the absence of the TCZ policy, individuals born in counties designated as TCZ would have been less likely to obtain high scores in high school entrance exam and therefore, less likely to attend a high quality high school. They would have also been less likely to opt for an academic high school, instead of a specialized/technical one which focuses on manual labor training. Projecting forward, we also suggest better future higher education and labor market outcomes, stemming from being able to attend academic and better quality high schools. Looking more specifically at the effects by gender and by socio-economic status, we find that important benefits associated with the TCZ policy relate to girls and to children born to low educated fathers. These results suggest that the environmental regulations may be used as a possible mechanism to reduce disparities in educational performance. However, we find no differential impacts between children exposed to the TCZ policy implementation at ages 1-5, in terms of the probability to attend a higher quality high school or an academic high school, although that does not imply the absence of positive effects for these age cohorts.

Bibliography

- Acemoglu, D. (1998). Why do new technologies complement skills? directed technical change and wage inequality. *The quarterly journal of economics*, 113(4):1055–1089.
- Adhvaryu, A., Bednar, S., Molina, T., Nguyen, Q., and Nyshadham, A. (2020). When it rains it pours: The long-run economic impacts of salt iodization in the united states. *Review of Economics and Statistics*, 102(2):395–407.
- Adnan, K. M., Ying, L., Sarker, S. A., Hafeez, M., Razzaq, A., and Raza, M. H. (2018). Adoption of contract farming and precautionary savings to manage the catastrophic risk of maize farming: Evidence from bangladesh. *Sustainability*, 11(1):29.
- Aguilar, A. and Vicarelli, M. (2011). El nino and mexican children: medium-term effects of early-life weather shocks on cognitive and health outcomes. *Cambridge, United States: Harvard University, Department of Economics. Manuscript.*
- Aizer, A., Currie, J., Simon, P., and Vivier, P. (2018). Do low levels of blood lead reduce children’s future test scores? *American Economic Journal: Applied Economics*, 10(1):307–41.
- Aizer, A., Eli, S., Ferrie, J., and Lleras-Muney, A. (2016a). The long-run impact of cash transfers to poor families. *American Economic Review*, 106(4):935–71.
- Aizer, A., Stroud, L., and Buka, S. (2016b). Maternal stress and child outcomes: Evidence from siblings. *Journal of Human Resources*, 51(3):523–555.
- Alderman, H. (1996). Saving and economic shocks in rural pakistan. *Journal of Development economics*, 51(2):343–365.
- Alderman, H. and Paxson, C. H. (1994). Do the poor insure? a synthesis of the literature on risk and consumption in developing countries. *Economics in a changing world*, pages 48–78.
- Almond, D., Edlund, L., Li, H., and Zhang, J. (2010). Long-term effects of early-life development: Evidence from the 1959 to 1961 china famine. In *The economic consequences of demographic change in East Asia*, pages 321–345. University of Chicago Press.
- Almond, D., Mazumder, B., and Van Ewijk, R. (2015). In utero ramadan exposure and children’s academic performance. *The Economic Journal*, 125(589):1501–1533.
- Attanasio, O., Meghir, C., and Nix, E. (2020). Human capital development and parental investment in india. *The Review of Economic Studies*, 87(6):2511–2541.
- Baiardi, D., Magnani, M., and Menegatti, M. (2020). The theory of precautionary saving: an overview of recent developments. *Review of Economics of the Household*, 18(2):513–542.

- Baird, S., Hicks, J. H., Kremer, M., and Miguel, E. (2016). Worms at work: Long-run impacts of a child health investment. *The quarterly journal of economics*, 131(4):1637–1680.
- Baker, M. and Milligan, K. (2016). Boy-girl differences in parental time investments: Evidence from three countries. *Journal of Human capital*, 10(4):399–441.
- Bande, R. and Riveiro, D. (2013). Private saving rates and macroeconomic uncertainty: evidence from spanish regional data. *The Economic and Social Review*, 44(3, Autumn):323–349.
- Banerjee, A. V., Cole, S., Duflo, E., and Linden, L. (2007). Remedying education: Evidence from two randomized experiments in india. *The Quarterly Journal of Economics*, 122(3):1235–1264.
- Banerjee, A. V. and Duflo, E. (2007). The economic lives of the poor. *Journal of economic perspectives*, 21(1):141–168.
- Barnum, H. N., Sabot, R. H., et al. (1977). *Education, employment probabilities and rural-urban migration in Tanzania*, volume 39. Publication Unit, World Bank.
- Becker, G. S. (1962). Investment in human capital: A theoretical analysis. *Journal of political economy*, 70(5, Part 2):9–49.
- Becker, G. S. (1964). Human capital (new york, national bureau of economic research, distributed by columbia university press). *Becker Human Capital 1964*.
- Becker, G. S. (2002). Human capital. *The concise encyclopedia of economics*, 2.
- Becker, G. S. (2009). *Human capital: A theoretical and empirical analysis, with special reference to education*. University of Chicago press.
- Becker, G. S., Murphy, K. M., and Tamura, R. (1990). Human capital, fertility, and economic growth. *Journal of political economy*, 98(5, Part 2):S12–S37.
- Becker, G. S. and Tomes, N. (1979). An equilibrium theory of the distribution of income and intergenerational mobility. *Journal of political Economy*, 87(6):1153–1189.
- Belli, P. C. and Appaix, O. (2003). *The economic benefits of investing in child health*. World Bank, Washington, DC.
- Benhassine, N., Devoto, F., Duflo, E., Dupas, P., and Pouliquen, V. (2015). Turning a shove into a nudge? a "labeled cash transfer" for education. *American Economic Journal: Economic Policy*, 7(3):86–125.
- Bharadwaj, P., Gibson, M., Zivin, J. G., and Neilson, C. (2017). Gray matters: Fetal pollution exposure and human capital formation. *Journal of the Association of Environmental and Resource Economists*, 4(2):505–542.
- Bharadwaj, P., Løken, K. V., and Neilson, C. (2013). Early life health interventions and academic achievement. *American Economic Review*, 103(5):1862–91.
- Billings, S. B. and Schnepel, K. T. (2018). Life after lead: Effects of early interventions for children exposed to lead. *American Economic Journal: Applied Economics*, 10(3):315–44.

- Black, S. E., Bütikofer, A., Devereux, P. J., and Salvanes, K. G. (2013). This is only a test? long-run impacts of prenatal exposure to radioactive fallout. Technical report, National Bureau of Economic Research.
- Bodvarsson, Ö. B. and Berg, H. V. d. (2013). The determinants of international migration: Theory. In *The economics of immigration*, pages 27–57. Springer.
- Bono, E. D., Francesconi, M., Kelly, Y., and Sacker, A. (2016). Early maternal time investment and early child outcomes. *The Economic Journal*, 126(596):F96–F135.
- Borghans, L., Duckworth, A. L., Heckman, J. J., and Ter Weel, B. (2008). The economics and psychology of personality traits. *Journal of human Resources*, 43(4):972–1059.
- Bowles, S., Gintis, H., and Osborne, M. (2001). The determinants of earnings: A behavioral approach. *Journal of economic literature*, 39(4):1137–1176.
- Bradley, E. H., Canavan, M., Rogan, E., Talbert-Slagle, K., Ndumele, C., Taylor, L., and Curry, L. A. (2016). Variation in health outcomes: the role of spending on social services, public health, and health care, 2000–09. *Health Affairs*, 35(5):760–768.
- Bryan, G., Chowdhury, S., and Mobarak, A. M. (2014). Underinvestment in a profitable technology: The case of seasonal migration in bangladesh. *Econometrica*, 82(5):1671–1748.
- Carneiro, P., Løken, K. V., and Salvanes, K. G. (2015). A flying start? maternity leave benefits and long-run outcomes of children. *Journal of Political Economy*, 123(2):365–412.
- Carroll, C. D. and Dunn, W. E. (1997). Unemployment expectations, jumping (s, s) triggers, and household balance sheets. *NBER macroeconomics annual*, 12:165–217.
- Carroll, C. D. and Samwick, A. A. (1998). How important is precautionary saving? *Review of Economics and statistics*, 80(3):410–419.
- Chang, H., Dong, X.-y., and MacPhail, F. (2011). Labor migration and time use patterns of the left-behind children and elderly in rural china. *World Development*, 39(12):2199–2210.
- Chang, T. Y., Graff Zivin, J., Gross, T., and Neidell, M. (2019). The effect of pollution on worker productivity: evidence from call center workers in china. *American Economic Journal: Applied Economics*, 11(1):151–72.
- Chen, F., Liu, H., Vikram, K., and Guo, Y. (2015). For better or worse: The health implications of marriage separation due to migration in rural china. *Demography*, 52(4):1321–1343.
- Chen, Y. J., Li, L., and Xiao, Y. (2020). Early-life exposure to tap water and the development of cognitive skills. *Journal of Human Resources*, pages 0917–9031R3.
- Chyi, H. and Zhou, B. (2014). The effects of tuition reforms on school enrollment in rural china. *Economics of Education Review*, 38:104–123.
- Coate, S. and Ravallion, M. (1993). Reciprocity without commitment: Characterization and performance of informal insurance arrangements. *Journal of development Economics*, 40(1):1–24.
- Cordero-Coma, J. and Esping-Andersen, G. (2018). Parental time dedication and children’s education. an analysis of west germany. *Research in Social Stratification and Mobility*, 55:1–12.

- Cortes, P. (2015). The feminization of international migration and its effects on the children left behind: Evidence from the philippines. *World Development*, 65:62–78.
- Cunha, F. and Heckman, J. (2007). The technology of skill formation. *American economic review*, 97(2):31–47.
- Cunha, F. and Heckman, J. J. (2009). The economics and psychology of inequality and human development. *Journal of the European Economic Association*, 7(2-3):320–364.
- Cunha, F., Heckman, J. J., and Schennach, S. M. (2010). Estimating the technology of cognitive and noncognitive skill formation. *Econometrica*, 78(3):883–931.
- Currie, J., Graff Zivin, J., Meckel, K., Neidell, M., and Schlenker, W. (2013). Something in the water: Contaminated drinking water and infant health. *Canadian Journal of Economics/Revue canadienne d'économique*, 46(3):791–810.
- Das, N., de Janvry, A., Mahmood, S., and Sadoulet, E. (2019). Migration as a risky enterprise: A diagnostic for bangladesh. *International Migration Review*, 53(3):900–929.
- De Neve, J.-W. and Fink, G. (2018). Children's education and parental old age survival—quasi-experimental evidence on the intergenerational effects of human capital investment. *Journal of health economics*, 58:76–89.
- Deng, Q., Lu, C., Norbäck, D., Bornehag, C.-G., Zhang, Y., Liu, W., Yuan, H., and Sundell, J. (2015). Early life exposure to ambient air pollution and childhood asthma in china. *Environmental research*, 143:83–92.
- Deschenes, O., Wang, H., Wang, S., and Zhang, P. (2020). The effect of air pollution on body weight and obesity: evidence from china. *Journal of Development Economics*, 145:102461.
- Dillon, A., Mueller, V., and Salau, S. (2011). Migratory responses to agricultural risk in northern nigeria. *American Journal of Agricultural Economics*, 93(4):1048–1061.
- Ding, S. and Knight, J. (2011). Why has china grown so fast? the role of physical and human capital formation. *Oxford Bulletin of Economics and Statistics*, 73(2):141–174.
- Djajić, S. and Milbourne, R. (1988). A general equilibrium model of guest-worker migration: The source-country perspective. *Journal of international economics*, 25(3-4):335–351.
- Du, Y., Park, A., and Wang, S. (2005). Migration and rural poverty in china. *Journal of comparative economics*, 33(4):688–709.
- Duflo, E. (2001). Schooling and labor market consequences of school construction in indonesia: Evidence from an unusual policy experiment. *American economic review*, 91(4):795–813.
- Duflo, E., Dupas, P., and Kremer, M. (2021). The impact of free secondary education: Experimental evidence from ghana. Technical report, National Bureau of Economic Research.
- Duflo, E., Hanna, R., and Ryan, S. P. (2012). Incentives work: Getting teachers to come to school. *American Economic Review*, 102(4):1241–78.
- Dustmann, C. (1995). Savings behavior of return migrants—a life-cycle analysis (vol. 115)(pp. 511–533). *Zeitschrift Fuer Wirtschafts-Und Sozialwissenschaften*.

- Dustmann, C. (2003). Return migration, wage differentials, and the optimal migration duration. *European Economic Review*, 47(2):353–369.
- Dustmann, C. and Kirchkamp, O. (2002). The optimal migration duration and activity choice after re-migration. *Journal of development economics*, 67(2):351–372.
- Eeckhoudt, L. and Schlesinger, H. (2006). Putting risk in its proper place. *American Economic Review*, 96(1):280–289.
- Ellsworth, L. (1989). Mutual insurance and non-market transactions among farmers in burkina faso.
- Fafchamps, M. and Lund, S. (2003). Risk-sharing networks in rural philippines. *Journal of development Economics*, 71(2):261–287.
- Fafchamps, M., Udry, C., and Czukas, K. (1998). Drought and saving in west africa: are livestock a buffer stock? *Journal of Development economics*, 55(2):273–305.
- Farag, M., Nandakumar, A., Wallack, S., Hodgkin, D., Gaumer, G., and Erbil, C. (2013). Health expenditures, health outcomes and the role of good governance. *International journal of health care finance and economics*, 13(1):33–52.
- Feng, Q., He, Q., and Loh, C.-P. A. (2022). The effect of childhood left-behind experience on individual’s income: evidence from china. *Applied Economics*, pages 1–14.
- Fiorini, M. and Keane, M. P. (2014). How the allocation of children’s time affects cognitive and noncognitive development. *Journal of Labor Economics*, 32(4):787–836.
- Foster, A. D. and Rosenzweig, M. R. (2001). Imperfect commitment, altruism, and the family: Evidence from transfer behavior in low-income rural areas. *Review of Economics and Statistics*, 83(3):389–407.
- Gao, Y., Li, L. P., Kim, J. H., Congdon, N., Lau, J., and Griffiths, S. (2010). The impact of parental migration on health status and health behaviours among left behind adolescent school children in china. *BMC public health*, 10(1):1–10.
- Gayle, G.-L., Golan, L., and Soytaş, M. (2018). Intergenerational mobility and the effects of parental education, time investment, and income on children’s educational attainment.
- Genicot, G. and Ray, D. (2003). Group formation in risk-sharing arrangements. *The Review of Economic Studies*, 70(1):87–113.
- Giles, J. (2006). Is life more risky in the open? household risk-coping and the opening of china’s labor markets. *Journal of Development Economics*, 81(1):25–60.
- Giles, J. and Yoo, K. (2007). Precautionary behavior, migrant networks, and household consumption decisions: An empirical analysis using household panel data from rural china. *The Review of Economics and Statistics*, 89(3):534–551.
- Grimard, F. (1997). Household consumption smoothing through ethnic ties: evidence from cote d’ivoire. *Journal of development Economics*, 53(2):391–422.
- Gröger, A. and Zylberberg, Y. (2016). Internal labor migration as a shock coping strategy: Evidence from a typhoon. *American Economic Journal: Applied Economics*, 8(2):123–53.

- Guiso, L., Jappelli, T., and Terlizzese, D. (1992). Earnings uncertainty and precautionary saving. *Journal of Monetary Economics*, 30(2):307–337.
- Hanushek, E. A. and Woessmann, L. (2015). *The knowledge capital of nations: Education and the economics of growth*. MIT press.
- Harris, J. R. and Todaro, M. P. (1970). Migration, unemployment and development: a two-sector analysis. *American Economic Review*, 60(1):126–142.
- Havnes, T. and Mogstad, M. (2011). No child left behind: Subsidized child care and children’s long-run outcomes. *American Economic Journal: Economic Policy*, 3(2):97–129.
- He, J., Liu, H., and Salvo, A. (2019). Severe air pollution and labor productivity: Evidence from industrial towns in china. *American Economic Journal: Applied Economics*, 11(1):173–201.
- Heckman, J. J. (2003). China’s investment in human capital. *Economic Development and Cultural Change*, 51(4):795–804.
- Heckman, J. J. (2005). China’s human capital investment. *China Economic Review*, 16(1):50–70.
- Heckman, J. J., Humphries, J. E., and Veramendi, G. (2015). The causal effects of education on earnings and health. *Unpublished manuscript, Department of Economics, University of Chicago*.
- Heckman, J. J., Humphries, J. E., and Veramendi, G. (2018). The nonmarket benefits of education and ability. *Journal of human capital*, 12(2):282–304.
- Heckman, J. J. and Rubinstein, Y. (2001). The importance of noncognitive skills: Lessons from the ged testing program. *American Economic Review*, 91(2):145–149.
- Heckman, J. J., Stixrud, J., and Urzua, S. (2006). The effects of cognitive and noncognitive abilities on labor market outcomes and social behavior. *Journal of Labor economics*, 24(3):411–482.
- Heckman, J. J. and Yi, J. (2012). Human capital, economic growth, and inequality in china. Technical report, National Bureau of Economic Research.
- Heissel, J. A., Persico, C., and Simon, D. (2022). Does pollution drive achievement? the effect of traffic pollution on academic performance. *Journal of Human Resources*, 57(3):747–776.
- Hill, J. K. (1987). Immigrant decisions concerning duration of stay and migratory frequency. *Journal of development economics*, 25(1):221–234.
- Ho, C. (2019). Child’s gender, parental monetary investments and care of elderly parents in china. *Review of Economics of the Household*, 17(3):741–774.
- Hongyi, L. and Huang, L. (2009). Health, education, and economic growth in china: Empirical findings and implications. *China Economic Review*, 20(3):374–387.
- Hsin, A. (2012). Is biology destiny? birth weight and differential parental treatment. *Demography*, 49(4):1385–1405.

- Hsu, W.-T. and Ma, L. (2021). Urbanization policy and economic development: A quantitative analysis of china's differential hukou reforms. *Regional Science and Urban Economics*, page 103639.
- Hu, B. Y., Wu, H., Winsler, A., Fan, X., and Song, Z. (2020). Parent migration and rural preschool children's early academic and social skill trajectories in china: Are 'left-behind' children really left behind? *Early Childhood Research Quarterly*, 51:317–328.
- Hu, F., Xu, Z., and Chen, Y. (2011). Circular migration, or permanent stay? evidence from china's rural–urban migration. *China Economic Review*, 22(1):64–74.
- Huggett, M., Ventura, G., and Yaron, A. (2011). Sources of lifetime inequality. *American Economic Review*, 101(7):2923–54.
- Isen, A., Rossin-Slater, M., and Walker, W. R. (2017). Every breath you take—every dollar you'll make: The long-term consequences of the clean air act of 1970. *Journal of Political Economy*, 125(3):848–902.
- Jalan, J. and Ravallion, M. (1999). Are the poor less well insured? evidence on vulnerability to income risk in rural china. *Journal of development economics*, 58(1):61–81.
- Jalan, J. and Ravallion, M. (2001). Behavioral responses to risk in rural china. *Journal of Development Economics*, 66(1):23–49.
- Janssens, W., Pradhan, M., de Groot, R., Sidze, E., Donfouet, H. P. P., and Abajobir, A. (2021). The short-term economic effects of covid-19 on low-income households in rural kenya: An analysis using weekly financial household data. *World Development*, 138:105280.
- Jensen, R. (2000). Agricultural volatility and investments in children. *American Economic Review*, 90(2):399–404.
- Joon-Ho, H. (1999). Consumption growth, income growth and earnings uncertainty: Simple cross-country evidence. *International Economic Journal*, 13(2):39–58.
- Kautz, T., Heckman, J. J., Diris, R., Ter Weel, B., and Borghans, L. (2014). Fostering and measuring skills: Improving cognitive and non-cognitive skills to promote lifetime success.
- Kimball, M. S. et al. (1990). Precautionary saving in the small and in the large. *Econometrica*, 58(1):53–73.
- Kinnan, C. (2022). Distinguishing barriers to insurance in thai villages. *Journal of Human Resources*, 57(1):44–78.
- Knight, J. and Song, L. (2005). *Towards a labour market in China*. OUP Oxford.
- Lee, J.-J. and Sawada, Y. (2010). Precautionary saving under liquidity constraints: Evidence from rural pakistan. *Journal of Development Economics*, 91(1):77–86.
- Lee, M.-H. (2011). Migration and children's welfare in china: The schooling and health of children left behind. *The Journal of Developing Areas*, pages 165–182.
- Leland, H. E. (1978). Saving and uncertainty: The precautionary demand for saving. In *Uncertainty in economics*, pages 127–139. Elsevier.
- Li, H., Loyalka, P., Rozelle, S., and Wu, B. (2017). Human capital and china's future growth. *Journal of Economic Perspectives*, 31(1):25–48.

- Li, W. and Zhang, K. (2019). Does air pollution crowd out foreign direct investment inflows? evidence from a quasi-natural experiment in china. *Environmental and Resource Economics*, 73(4):1387–1414.
- Liang, W. and Yang, M. (2019). Urbanization, economic growth and environmental pollution: Evidence from china. *Sustainable Computing: Informatics and Systems*, 21:1–9.
- Liang, Z. (2001). The age of migration in china. *Population and development review*, 27(3):499–524.
- Ligon, E., Thomas, J. P., and Worrall, T. (2000). Mutual insurance, individual savings, and limited commitment. *Review of Economic Dynamics*, 3(2):216–246.
- Linnemayr, S. and Alderman, H. (2011). Almost random: Evaluating a large-scale randomized nutrition program in the presence of crossover. *Journal of Development Economics*, 96(1):106–114.
- Lu, H., Yue, A., Chen, H., and Long, R. (2018). Could smog pollution lead to the migration of local skilled workers? evidence from the jing-jin-ji region in china. *Resources, conservation and recycling*, 130:177–187.
- Lu, Z. and Pang, X. (2022). The impact of parental migration on offspring’s education investment: Evidence from left-behind children in china. *Sustainability*, 14(10):6257.
- Lucas, R. E. (1988). On the mechanics of economic development. *Journal of monetary economics*, 22(1):3–42.
- Lusardi, A. (1997). Precautionary saving and subjective earnings variance. *economics letters*, 57(3):319–326.
- Mao, M., Zang, L., and Zhang, H. (2020). The effects of parental absence on children development: Evidence from left-behind children in china. *International Journal of Environmental Research and Public Health*, 17(18):6770.
- Mayda, A. M. (2010). International migration: A panel data analysis of the determinants of bilateral flows. *Journal of population economics*, 23(4):1249–1274.
- Mazzocco, M. and Saini, S. (2012). Testing efficient risk sharing with heterogeneous risk preferences. *American Economic Review*, 102(1):428–68.
- Menegatti, M. (2010). Uncertainty and consumption: new evidence in oecd countries. *Bulletin of Economic Research*, 62(3):227–242.
- Meng, X. (2003). Unemployment, consumption smoothing, and precautionary saving in urban china. *Journal of Comparative Economics*, 31(3):465–485.
- Meng, X. and Yamauchi, C. (2017). Children of migrants: The cumulative impact of parental migration on children’s education and health outcomes in china. *Demography*, 54(5):1677–1714.
- Mesnard, A. (2004). Temporary migration and capital market imperfections. *Oxford economic papers*, 56(2):242–262.
- Midouhas, E., Kokosi, T., and Flouri, E. (2018). Outdoor and indoor air quality and cognitive ability in young children. *Environmental research*, 161:321–328.

- Minale, L. (2018). Agricultural productivity shocks, labour reallocation and rural–urban migration in china. *Journal of Economic Geography*, 18(4):795–821.
- Mishra, A. K., Uematsu, H., and Matthew Fannin, J. (2013). Measuring precautionary wealth using cross-sectional data: the case of farm households. *Review of Economics of the Household*, 11(1):131–141.
- Mody, A., Ohnsorge, F., and Sandri, D. (2012). Precautionary savings in the great recession. *IMF Economic Review*, 60(1):114–138.
- Morduch, J. (2006). Microinsurance: The next revolution. *Understanding poverty*, pages 337–356.
- Murnane, R., Willett, J. B., and Levy, F. (1995). The growing importance of cognitive skills in wage determination.
- NBS (2019). China statistical yearbook. Available at <http://www.stats.gov.cn/tjsj/ndsj/2019/indexeh.htm>.
- Park, A. (2006). Risk and household grain management in developing countries. *The Economic Journal*, 116(514):1088–1115.
- Persson, P. and Rossin-Slater, M. (2018). Family ruptures, stress, and the mental health of the next generation. *American economic review*, 108(4-5):1214–52.
- Pinto-Jayawardena, K. et al. (2006). Left behind, left out: The impact on children and families of mothers migrating for work abroad: Summary report. Technical report, Save the Children in Sri Lanka, Colombo.
- Pujol, M. (1984). Gender and class in marshall's" principles of economics". *Cambridge Journal of Economics*, 8(3):217–234.
- Qin, J. and Albin, B. (2010). The mental health of children left behind in rural china by migrating parents: A literature review. *Journal of Public Mental Health*.
- Qin, Y. and Zhu, H. (2018). Run away? air pollution and emigration interests in china. *Journal of Population Economics*, 31(1):235–266.
- Romer, P. M. (1986). Increasing returns and long-run growth. *Journal of political economy*, 94(5):1002–1037.
- Rosenzweig, M. R. and Stark, O. (1989). Consumption smoothing, migration, and marriage: Evidence from rural india. *Journal of political Economy*, 97(4):905–926.
- Rosenzweig, M. R. and Wolpin, K. I. (1993). Credit market constraints, consumption smoothing, and the accumulation of durable production assets in low-income countries: Investments in bullocks in india. *Journal of political economy*, 101(2):223–244.
- Schultz, T. W. (1961). Investment in human capital. *The American economic review*, 51(1):1–17.
- Shi, X. (2016). The impact of educational fee reduction reform on school enrolment in rural china. *The Journal of Development Studies*, 52(12):1791–1809.
- Sjaastad, L. A. (1962). The costs and returns of human migration. *Journal of political Economy*, 70(5, Part 2):80–93.

- Smith, A. (1776). The wealth of nations (new york: Modern library, 1937). *Originally published*, 3.
- Smyth, R., Mishra, V., and Qian, X. (2008). The environment and well-being in urban china. *Ecological economics*, 68(1-2):547–555.
- Song, Y. (2014). What should economists know about the current chinese hukou system? *China Economic Review*, 29:200–212.
- Stark, O. and Bloom, D. E. (1985). The new economics of labor migration. *The american Economic review*, 75(2):173–178.
- Stark, O. and Levhari, D. (1982). On migration and risk in LDCs. *Economic Development and Cultural Change*, 31(1):191–196.
- Stark, O. and Lucas, R. E. (1988). Migration, remittances, and the family. *Economic development and cultural change*, 36(3):465–481.
- Su, Y. and Liu, Z. (2016). The impact of foreign direct investment and human capital on economic growth: Evidence from chinese cities. *China Economic Review*, 37:97–109.
- Tang, D., Li, T.-y., Liu, J. J., Zhou, Z.-j., Yuan, T., Chen, Y.-h., Rauh, V. A., Xie, J., and Perera, F. (2008). Effects of prenatal exposure to coal-burning pollutants on children’s development in china. *Environmental health perspectives*, 116(5):674–679.
- Thomsen, M. K. (2015). Parental time investments in children: Evidence from denmark. *Acta Sociologica*, 58(3):249–263.
- Tobler, P. N. and Weber, E. U. (2014). Valuation for risky and uncertain choices. In *Neuroeconomics*, pages 149–172. Elsevier.
- Todaro, M. P. (1969). A model of labor migration and urban unemployment in less developed countries. *American Economic Review*, 59(1):138–148.
- Tong, Y., Chen, F., and Shu, B. (2019). Spousal migration and married adults’ psychological distress in rural china: The roles of intimacy, autonomy and responsibility. *Social science research*, 83:102312.
- Townsend, R. M. (1994). Risk and insurance in village india. *Econometrica: journal of the Econometric Society*, pages 539–591.
- Udry, C. (1994). Risk and insurance in a rural credit market: An empirical investigation in northern nigeria. *The Review of Economic Studies*, 61(3):495–526.
- Ullah, R., Jourdain, D., Shivakoti, G. P., and Dhakal, S. (2015). Managing catastrophic risks in agriculture: Simultaneous adoption of diversification and precautionary savings. *International Journal of Disaster Risk Reduction*, 12:268–277.
- UNICEF (2018). Country office annual report 2018, china. Available at: https://www.unicef.org/about/annualreport/files/China_2018_COAR.pdf.
- UNICEF (2018). *UNICEF 2018 China Office Annual Report*. Available at https://www.unicef.org/about/annualreport/files/China_2018_COAR.pdf.
- Venkataramani, A. S. (2012). Early life exposure to malaria and cognition in adulthood: evidence from mexico. *Journal of health economics*, 31(5):767–780.

- von Hinke Kessler Scholder, S., Wehby, G. L., Lewis, S., and Zuccolo, L. (2014). Alcohol exposure in utero and child academic achievement. *The Economic Journal*, 124(576):634–667.
- Wang, H., Cheng, Z., Wang, B. Z., and Chen, Y. (2021). Childhood left-behind experience and labour market outcomes in china. *Journal of Business Research*, 132:196–207.
- Wang, S. X. (2014). The effect of parental migration on the educational attainment of their left-behind children in rural china. *The BE Journal of Economic Analysis & Policy*, 14(3):1037–1080.
- Wen, M. and Lin, D. (2012). Child development in rural china: Children left behind by their migrant parents and children of nonmigrant families. *Child development*, 83(1):120–136.
- WHO and UNICEF (2015). *Progress on sanitation and drinking water: 2015 update and MDG assessment*. World Health Organization.
- Williams, A. M. and Baláž, V. (2012). Migration, risk, and uncertainty: Theoretical perspectives. *Population, Space and Place*, 18(2):167–180.
- Xiang, A., Jiang, D., and Zhong, Z. (2016). The impact of rural–urban migration on the health of the left-behind parents. *China Economic Review*, 37:126–139.
- Xiao, Y., Li, L., and Zhao, L. (2017). Education on the cheap: The long-run effects of a free compulsory education reform in rural china. *Journal of Comparative Economics*, 45(3):544–562.
- Yang, D. and Choi, H. (2007). Are remittances insurance? evidence from rainfall shocks in the philippines. *The World Bank Economic Review*, 21(2):219–248.
- Yeung, W. J., Linver, M. R., and Brooks-Gunn, J. (2002). How money matters for young children’s development: Parental investment and family processes. *Child development*, 73(6):1861–1879.
- Zeng, Y., Cao, Y., Qiao, X., Seyler, B. C., and Tang, Y. (2019). Air pollution reduction in china: Recent success but great challenge for the future. *Science of the Total Environment*, 663:329–337.
- Zhang, H., Behrman, J. R., Fan, C. S., Wei, X., and Zhang, J. (2014). Does parental absence reduce cognitive achievements? evidence from rural china. *Journal of Development Economics*, 111:181–195.
- Zhang, J. (2012). The impact of water quality on health: Evidence from the drinking water infrastructure program in rural china. *Journal of health economics*, 31(1):122–134.
- Zhang, J. and Xu, L. C. (2016). The long-run effects of treated water on education: The rural drinking water program in china. *Journal of Development Economics*, 122:1–15.
- Zhang, J. J., Hu, W., Wei, F., Wu, G., Korn, L. R., and Chapman, R. S. (2002). Children’s respiratory morbidity prevalence in relation to air pollution in four chinese cities. *Environmental health perspectives*, 110(9):961–967.
- Zhang, X., Chen, X., and Zhang, X. (2018a). The impact of exposure to air pollution on cognitive performance. *Proceedings of the National Academy of Sciences*, 115(37):9193–9197.
- Zhang, X., Zhang, X., and Chen, X. (2017). Valuing air quality using happiness data: the case of china. *Ecological economics*, 137:29–36.

- Zhang, Z., Hao, Y., and Lu, Z.-N. (2018b). Does environmental pollution affect labor supply? an empirical analysis based on 112 cities in china. *Journal of Cleaner Production*, 190:378–387.
- Zhao, Q., Yu, X., Wang, X., and Glauben, T. (2014). The impact of parental migration on children’s school performance in rural china. *China Economic Review*, 31:43–54.
- Zheng, X., Fang, Z., Wang, Y., and Fang, X. (2022). When left-behind children become adults and parents: The long-term human capital consequences of parental absence in china. *China Economic Review*, page 101821.
- Zhou, J., Arundel, R., Zhang, S., He, Q., and Yang, Y. (2021). Intra-national citizenship and dual-hukou strategies among migrant families in china. *Habitat International*, 108:102311.
- Zhou, M., Murphy, R., and Tao, R. (2014). Effects of parents’ migration on the education of children left behind in rural china. *Population and Development Review*, 40(2):273–292.
- Zhu, N. (2002). The impacts of income gaps on migration decisions in china. *China Economic Review*, 13(2-3):213–230.

Chapter 1

Risks and optimal migration duration: The role of higher order risk attitudes

1.1 Introduction

Temporary labor mobility characterizes migration, both internationally and domestically, in many countries and regions worldwide (IOM, 2020). Contrary to what would be expected, migrations can be temporary even in the absence of restrictions on the duration of stay in the destination country. An estimated 20 to 50 percent of migrants in the OECD countries were found to leave the host country within 5 years of arrival (OECD, 2008). Previous theoretical literature has reported various factors that rationalize the return of migrants, despite higher earnings in the destination country (see Dustmann and Görlach, 2016). However, little is known about the factors that affect the duration of the migrants' stay in the destination country. Understanding migration's duration is crucial since it determines various important economic behaviors, such as consumption, savings and human capital investments, that may have substantial effects not only for migrants and their households, but also for populations of the two countries, in terms of remittances, brain drain, fiscal impacts and others (see Dustmann and Görlach, 2016).

Previous theoretical studies showed that migration duration depends crucially on future income streams in the home- and destination countries. However, income is, generally, strongly affected by risk both in developing and developed countries. In this paper, we investigate the effects of risks on the migration duration, in the specific case of migrant parents with children being left behind in the home country. Previous theoretical literature has long associated uncertainty and risks to either migration decisions or other economic decisions in a migration context (e.g., Stark and Levhari, 1982; Katz and Stark,

1986; Galor and Stark, 1991; Dustmann, 1997; Daveri and Faini, 1999; Chen et al., 2003). This paper, however, differs from previous work in at least two ways. First, the particular effect of income risks on the migration duration, for parents with left-behind children, has not been previously investigated. This type of migration is a widespread phenomenon as has been shown by the growing number of left-behind children around the world. In China, for example, an estimated 69 million children were left behind by one or both parents migrating to cities in 2015, accounting for about one third of all rural children in China (UNICEF, 2018). This number was approximated to 1 million in Sri Lanka in 2005 (Pinto-Jayawardena et al., 2006), and to about 1.5 to 3 million in the Philippines (Cortes, 2015). This loss of parental time has been shown to induce non-monetary costs for the left-behind children, generating troubling consequences for their education and cognitive ability (e.g., Antman, 2013; Nguyen, 2016), health and nutrition (e.g., Antman, 2013; Nguyen, 2016) and their socio-psychological behavior (e.g., Fellmeth et al., 2018). Given these additional costs compared to other migrants, cross-effects between income and children’s human capital in determining migration duration may be in place.¹ For this reason and based on Myerson (2017), we consider that the parents’ preferences are defined over his own income and his child’s human capital.²

Second, understanding the complex effects of income riskiness on migration duration dates back to the paper by Dustmann (1997), where the effect of income risk is compared to a situation with no uncertainty, but he limited his analysis to Taylor approximations of order two, which is equivalent to considering *weak* risks. As a consequence, he only compares risk levels à la Rothschild–Stiglitz (Rothschild and Stiglitz, 1970). In this paper, we extend the analysis to the case of increases in risk that imply different kinds of modifications in the migrants’ incomes’ distributions, which is new with respect to the literature. This is important as workers usually face situations that scale up the level of their labor

¹As child human capital is a multidimensional variable (Attanasio, 2015), three dimensions may be considered: health and nutritional status, education and socio-emotional skills. These dimensions vary over time according to a process that depends on three elements: the previous levels of the dimensions, environmental variables that are not varying over time and finally the investments by parents or institutions. Investments may affect different child outcomes differently, which raises the problem of how to aggregate these different effects in order to get the overall impact. For simplicity, in our model, we follow the theoretical literature on intergenerational mobility in using a summary metric of the child human capital status (see e.g., Becker et al., 2018).

²In the theoretical literature of migration, Dustmann (2003a), focusing on the case where all family members are migrants and where the parent has to make a decision about a return to the home country, considers a parent’s utility function defined over his consumption and the child’s consumption. Dustmann and Görlach (2016) also propose that their theoretical model for migration duration can be extended to the case where the consumption of left-behind family members is added to the migrant’s utility. Myerson (2017), investigating the sensitivity of the child’s human capital to parental migration, models the parental preferences over income and child human capital.

income risk, rather than moving from a non-risky to a risky situation. Many OECD countries, for example, were shown to have undergone, recently, increasing dispersion in wages due to globalization and digitalization (Berlingieri et al., 2017), suggesting greater financial uncertainty faced by workers. Moreover, we also examine the ex-ante migrant parents' responses to a risk on the savings accumulated at the destination country and to a non-monetary risk on their children's human capital.

To carry out our analysis, we build a model of temporary migration that is relatively close, in terms of the key assumptions of lifetime maximization framework and endogenous migration duration, to a type of models considered in the literature (see e.g., Djajić and Milbourne, 1988; Dustmann, 1995; Stark et al., 1997; Dustmann, 1999; Dustmann and Kirchkamp, 2002; Dustmann, 2003b; Mesnard, 2004). However, our model presents three main differences. First, contrary to the above studies, we focus on the temporary migration of parents when children are left behind. Second, while the models in the above works define migration duration with a time variable and represent it, in the maximization problem, as a multiplier of the utility enjoyed at the destination country, we model the migration duration as the equivalent of the decrease in the child human capital caused by the absence of the migrant parent. The last difference is related to the maximization problem of the migrant. While previous models define the optimal migration duration as the solution of a lifetime span allocation problem between migration and non-migration, we model the optimal migration duration as the solution of a resource transfer problem from the sub-period of migration to the sub-period of non-migration.³

Our work makes a contribution to the understanding of temporary migrants' behavior. First, we provide a new perspective on the effect of income differentials on migration duration under certainty. We particularly confirm, in a new context, the results of the previous literature showing that considering income differential on its own may result in misleading implications with respect to the stock of migrants in the destination country (Carrington et al., 1996; Dustmann, 2003b). Focusing on temporary migration of parents, we find that a decrease in the home country's income always increases the optimal migration duration. However, an increase in the destination country's income has an ambiguous effect. Migration duration may, therefore, decrease if income differentials between home- and destination countries increase, leading to a reduction in the migration population, for a constant inflow of migrants. We show that such a behavior can be driven by the sign of the interaction between human capital of children and wealth in migrating parents' utility

³There exists another type of models in the migration literature where the migration duration is not a choice variable in the model and where the optimal length of stay is determined in the postmigration stage (see e.g., Dustmann and Görlach, 2016).

function, referred to as their correlation attitude.⁴ The importance of the decision maker's correlation attitude has been emphasized in the theoretical economic decision literature in topics including savings, health and portfolio decisions (e.g., Bleichrodt et al., 2003; Eeckhoudt et al., 2007; Crainich et al., 2017; Liu and Menegatti, 2019a).

Second, we provide a further important mechanism for the effects of increases in risk on the migration duration of risk averse parents. Although intuition suggests, based on the risk aversion assumption, that migrant parents will always run away from increases in income riskiness, we show, in this paper, that this is not always the case. Risk aversion or correlation aversion are sufficient to generate a change in the parents' migration duration in the face of an increase in the unemployment risk. However, the sign of the effect of an increase in other types of income risk, which imply changes in higher order moments, is less straightforward and its sign cannot be determined by risk aversion. We provide conditions including higher order risk preferences that ensure, under any type of income risk, a precautionary migration motive for risk averse migrant parents. We also show that depending on the sign of these preferences, the sign of income risk's effect on the migration duration is determined. Under these conditions, an increase in the destination country's income risk or a decrease in the home country's income risk may lead to longer migration cycles. Similar conditions, following changes in the accumulated savings risk and in the migrant's child human capital risk, are also produced. Empirical work has long focused on the importance of risk aversion in the migration decision-making process (e.g., Jaeger et al., 2010; Dustmann et al., 2020), our results suggest that future research should also consider (cross-)prudence, (cross-)temperance and other higher order risk attitudes.⁵ The later may be important both for future research on the effects of risk on the migration duration and for informing public policy-making.

The above two results show the relevance of cross-effects in the particular case of migrant parents, compared to other types of migrants, in determining migration duration, both under certainty and under riskiness. This is new to the literature of temporary migration and suggests the importance of considering information on parents' preferences carrying cross-effects between the income and children's human capital in future empirical research.

The remainder of the paper is organized as follows. In section 1.2, we introduce the basic model with no risks. Section 1.3 investigates the effect of the introduction of income,

⁴In this case, the sign of the parent's correlation attitude is given by the direction of the variation in the marginal utility of child human capital, following an increase in the income abroad.

⁵Prudence and temperance are related to a positive third and a negative fourth derivatives of the utility function under expected utility, respectively (Kimball et al., 1990; Kimball, 1992).

savings and child human capital risks on the optimal migration duration. Section 1.4 generalizes the results. Section 1.5 shows the applicability of our results in the empirical work. Section 1.6 concludes.

1.2 Optimal migration decision

We consider a parent with at least one child. The parent (the decision maker in our model) has preferences represented by the bivariate utility function $G(y, Z)$, where y denotes income and Z the child human capital. We assume that G is n times continuously differentiable with respect to y and Z .⁶ G is strictly increasing and concave in each argument, $G^{(1,0)} > 0$, $G^{(0,1)} > 0$, $G^{(2,0)} < 0$ and $G^{(0,2)} < 0$: the migrant parent's preferences are nonsatiated and risk-averse with respect to income and child human capital. We do not introduce any assumption on the interaction between income and child human capital, i.e., on the sign of the cross-second derivatives of G . Thus, we consider the three possible cases: $G^{(1,1)} = 0$, $G^{(1,1)} < 0$ and $G^{(1,1)} > 0$. In the terminology of Epstein and Tanny (1980), the migrant parent is said to be correlation averse (correlation neutral, correlation loving) if $G^{(1,1)} < 0$ ($= 0$, > 0).⁷ For such a decision maker, the marginal utility of income is lower (unchanged, higher) when the child has higher levels of human capital. Depending on whether preferences are correlation loving or averse, the child human capital can be a complement or a substitute for income.

We consider a model with two periods. At the beginning of period 1, the parent is offered the option to migrate to a country of destination, and thus has to choose his migration duration. In period 2, he returns to the home country. During migration, the parent earns higher wages and is able to make savings, which are used to increase income of period 2. His absence implies, however, a non-monetary cost suffered by the left-behind child in terms of human capital.⁸

Under the assumption that a longer parental migration duration implies a higher deterioration in the child's human capital (see e.g., Zhou et al., 2014; Cheng and Sun, 2015), choosing the migration duration, d , amounts to choosing a level of reduction in

⁶The partial and the cross-derivatives $f^{(k_1, k_2)}$ of a function f with two arguments x_1 and x_2 are given by the following expression: $f^{(k_1, k_2)}(x_1, x_2) = \frac{\partial^{k_1+k_2} f(x_1, x_2)}{\partial x_1^{k_1} \partial x_2^{k_2}}$, $\forall k_1 \geq N, \forall k_2 \geq N$.

⁷No particular functional form of the parental utility function is adopted, as the later is related to the sign of the parents' correlation attitude. See Appendix 1.D for examples of the parental utility function.

⁸In the absence of remittances, this constitutes the main effect on the human capital of the child. If the parent transfers resources that guarantee higher monetary investments for the child's human capital, a distinct positive effect is also possible. However, the overall effect of migration, being positive or negative, would remain ambiguous. In our model, we do not consider the effect of remittances.

the child's human capital, m , such that $m = f(d)$ and $f'(d) > 0$. The sacrifice in the child's human capital allows a benefit in terms of an increase in wealth of period 2 due to the parent's accumulated savings in the destination country, $g(m)$. Under the above assumptions, the objective of the decision maker is to maximize his lifetime utility:

$$\text{Max}_m W(m) = U(y_1, Z_1 - m) + \beta V(y_2 + g(m), Z_2) \quad (1.1)$$

where U and V are the utility functions of periods 1 and 2, respectively, β is the discount factor, y_i is the income level of period i ($i = 1, 2$), and Z_i is the child human capital level in period i ($i = 1, 2$). In what follows, we denote the optimal level of migration duration by m^* . We assume that $g(0) = 0$, $g'(m) > 0$ and $g''(m) \leq 0$ for all levels of m , i.e., an increase in m increases the accumulated savings in the destination country but at a decreasing rate.⁹

In this paper, we model the choice of migration duration as a resource transfer problem from the first to the second period. In this sense, our model comes close to a savings problem with two dimensions where the second argument is a non-monetary variable, usually health status or environmental quality (see e.g., Courbage and Rey, 2007; Menegatti, 2009b), and to a tertiary prevention model (Eeckhoudt et al., 2007).¹⁰ The amount that the decision maker renounces and the benefit he gets, in these models, are expressed in the same unit. Our model differs from that in the sense that the decision maker gives up an amount expressed in non-monetary units (the child human capital), as in the tertiary prevention model, while the benefit obtained in period 2 is expressed in monetary units, as in the saving model. In this sense, our model is symmetric to the health investment model studied, for example, by Denuit et al. (2011) and Liu and Menegatti (2019b), where the decision maker endures a monetary cost in order to get a better health status in the future.

The first-order condition (FOC) for a maximum ($W'(m) = 0$) is given by

$$-U^{(0,1)}(y_1, Z_1 - m) + \beta g'(m)V^{(1,0)}(y_2 + g(m), Z_2) = 0.$$

The first part of the above equation, $U^{(0,1)}(y_1, Z_1 - m)$, represents the cost of remaining one additional unit of time abroad in terms of forgone utility, induced by being separated

⁹We assume an increasing and a concave relationship between earnings and migration duration (see e.g., Dustmann, 1993; Beenstock et al., 2010).

¹⁰"Tertiary prevention activities involve treating an established disease or chronic illness." Eeckhoudt et al. (2007). In such a model, the decision maker "invests" in tertiary prevention care, which reduces his health by a level equivalent to the type of care chosen, but, in return, increases the status of his future health.

from the child during that period. It is positive given our assumption on U , and increases in m . The second term, $g'(m)V^{(1,0)}(y_2 + g(m), Z_2)$, is the benefit of staying a further unit of time in the destination country. It is also positive, given our assumptions on V and g , but decreases in m . It is easy to show that the difference in benefit and cost of one additional unit of time abroad decreases in m ($W''(m) < 0, \forall m$), therefore, the optimal level of m^* is fully determined by the FOC:

$$-U^{(0,1)}(y_1, Z_1 - m^*) + \beta g'(m^*)V^{(1,0)}(y_2 + g(m^*), Z_2) = 0 \quad (1.2)$$

The migrant parent returns, therefore, when costs of remaining an extra unit of time in destination are equal to the benefits of doing so.¹¹

The parent migrates ($m^* > 0$) if the first unit of time's utility in the destination country is positive, i.e., $W'(0) > 0$, equivalently if $\beta g'(0)V^{(1,0)}(y_2, Z_2) > U^{(0,1)}(y_1, Z_1)$.¹² Particularly, the parent will migrate whenever his satisfaction from the present value of $g'(0)$ additional units of income in the future (when back in the home country) is strictly higher than the satisfaction he gets from each additional unit of the child's human capital during his migration. In our model, the parent will never stay permanently in the destination country because the marginal utility of spending the last moment in the migrant's life, in the destination country, will always be negative.¹³ We assume that these conditions are verified in all what follows.

The change in the optimal migration duration as a result of the changes in the destination- and home country incomes and child human capital levels are summarized in the following proposition (details of calculations are presented in Appendix 1.A).

Proposition 1 *The optimal migration duration (m^*)*

(i) *decreases with the home country income (y_2) and increases with the child's human capital level during the parent's migration (Z_1),*

(ii) *increases [remains constant, decreases] with the destination country income (y_1) if the migrant parent is correlation averse [neutral, loving] during his migration ($U^{(1,1)} < 0$) [/ $U^{(1,1)} = 0, U^{(1,1)} > 0$],*

¹¹In our theoretical model, we only study the case of an interior solution. Corner solutions of permanent migration where the migrant parent never returns and of no migration where the parent never migrates are not considered.

¹²Given our assumption that $g'(0) > 0$.

¹³If $d = d_{max}$, then $m = m_{max}$, where d_{max} is the maximum duration of migration for the parent, i.e., given the migration time, he only returns when he dies or at the end of his working life. Given our assumptions, g' is a decreasing and a strictly positive function, therefore, $\lim_{m \rightarrow m_{max}} g'(m) = 0$, thus $\lim_{m \rightarrow m_{max}} W'(m) = U^{(0,1)}(y_1, Z_1 m_{max}) < 0$.

(iii) decreases [remains constant, increases] with the child's human capital level after the return of the migrant parent (Z_2) if the migrant parent is correlation averse [neutral, loving] ($V^{(1,1)} < 0$) [$V^{(1,1)} = 0$, $V^{(1,1)} > 0$].

Intuitive explanations of these results are the following. An increase in the home country income y_2 decreases the home country marginal utility of wealth, leading to a reduction in the optimal migration duration, *ceteris paribus*. Now consider an increase in the level of the child human capital during the parent's migration Z_1 , due, for example, to government policies that increase services for left-behind children with migrating parents.¹⁴ In this case, the marginal utility of child human capital will be decreasing, inducing, therefore, an increase in the optimal migration duration, *ceteris paribus*.

The comparative statics show that, contrarily to the variation of m^* with respect to y_2 and Z_1 , the variation of m^* with respect to y_1 and Z_2 depends on the correlation attitude of the migrant parent, *ceteris paribus*. If the migrant parent's income in the destination country y_1 increases, then one would expect that his migration duration will increase. However, (ii) shows that it is not necessarily the case. As the migration duration is negatively related to the child human capital, the optimal migration duration depends on how the increase in y_1 affects the marginal utility of child human capital ($U^{(1,1)}$), *ceteris paribus*. This result implies that the effect of a sudden increase in income on the migration duration of parents with the same characteristics and from the same origin country, but with different child human capital levels, may be different, if higher incomes affect differently the satisfaction they get from each additional unit of child human capital. It also suggests that a parent faced with two destinations with different levels of earnings will stay less time in the destination where the income is higher, if the parent is correlation loving, and vice versa.

In the case where the child human capital Z_2 is expected to increase upon the return of the parent, the variation of the optimal migration depends on how the marginal utility of income reacts to an increase in Z_2 . The length of the parent migration would be reduced in the unique case where the migrant parent is correlation averse ($V^{(1,1)} < 0$), *ceteris paribus*.

1.3 Migration duration decision under risk

In this section, we extend the previous simple framework to a risky environment. More precisely, we introduce monetary or non-monetary risks and investigate their effects on

¹⁴The child protection program in China as an example (Man et al., 2017).

the migration duration compared to a situation with no risks.

1.3.1 Income risks

Income risk for workers may have various sources. It may occur at the aggregate level, including, for example, political instability, economic crises or adverse weather variability for agricultural activities. Workers may also face idiosyncratic income risks, such as in the case of earnings that include commissions, future incomes that are not known in advance as in the case of self-employment, unemployment risk, and risks of unfair dismissal or non-payment if working in the informal sector. In China, for example, one important source of insecurity for migrant workers is the risk of delayed payments and non-payment problems (Chan, 2005). Moreover, as discussed by Tressler and Menezes (1980), even when nominal wages are known with certainty, if workers cannot accurately predict inflation, real wages will also become uncertain.

We analyze two cases: a risk on the destination country's income and a risk on the home country's income.

Risk on the destination country income

The migrant parent is now faced with a risk on his destination country's income ($y_1 + \tilde{\epsilon}_{1w}$). We investigate how the riskiness of migration affects the parent's stay abroad compared to a situation with no risks, *ceteris paribus*.

The parent's maximization problem in the absence of risk is given by Eq. (1.1). In the case of an income risk in the destination country, he maximizes the following lifetime utility at the beginning of period 1

$$W_{\tilde{\epsilon}_{1w}}(m) = E[U(y_1 + \tilde{\epsilon}_{1w}, Z_1 - m)] + \beta V(y_2 + g(m), Z_2). \quad (1.3)$$

where E denotes the expectation operator over the random variable $\tilde{\epsilon}_{1w}$. We denote by $m_{\tilde{\epsilon}_{1w}}^*$ the length of the parent's migration in this case, implying a FOC given by

$$W'_{\tilde{\epsilon}_{1w}}(m_{\tilde{\epsilon}_{1w}}^*) = -E[U^{(0,1)}(y_1 + \tilde{\epsilon}_{1w}, Z_1 - m_{\tilde{\epsilon}_{1w}}^*)] + \beta g'(m_{\tilde{\epsilon}_{1w}}^*) V^{(1,0)}(y_2 + g(m_{\tilde{\epsilon}_{1w}}^*), Z_2) = 0. \quad (1.4)$$

In our analysis, we distinguish two types of risks: an unfavorable pure risk and a speculative risk. Pure risk refers to a situation where no gain can be realized, loss is possible while the best outcome is the absence of loss. The expected gain, in this case, is, therefore, negative. We can consider, for example, an unemployment risk, $\tilde{\epsilon}_{1w} = [0, -k; 1 - p, p]$, where p is the probability of unemployment ($0 < p < 1$) and k is the decrease in income following the unemployment ($k > 0$). Speculative risk, however, refers

to a situation where the future outcome is subject to changes that may be higher or lower than anticipated. We consider the case of a zero-mean speculative risk, such that $E[\tilde{\epsilon}_{1w}] = 0$.

Considering equations (1.2) and (1.4), we obtain the following results.

Proposition 2 *Under an unfavorable pure risk in the country of destination [first period], a migrant parent will stay longer (shorter) at destination than with no such risk, $m_{\epsilon_{1w}}^* \geq (\leq) m^*$, if $U^{(1,1)} \geq (\leq) 0$.*

Under a zero-mean risk on the country of destination's income [first period], a migrant parent will stay longer (shorter) at destination than with no such risk, $m_{\epsilon_{1w}}^ \geq (\leq) m^*$, if $U^{(2,1)} \leq (\geq) 0$.*

Proof See Appendix 1.B.

We provide in Proposition 2 sufficient conditions that govern the direction of the migration duration variation, when a migrant parent is faced with an unfavorable pure risk or a zero-mean income risk, in the destination country. An unfavorable pure risk increases the migration duration of migrant parents only if they are correlation averse ($U^{(1,1)} \geq 0$), i.e., those for whom a higher human capital level of their children increases their marginal utility of income.

The proposition also shows that all risk averse migrant parents may dislike changes in their incomes' distribution through a zero-mean risk, but not all of them would decrease their migration duration. Their behavior depends on the sign of $U^{(2,1)}$. We refer to $U^{(2,1)}$ as the 'cross-prudence in the child human capital', following the previous literature calling $U^{(2,1)}$ the 'cross-prudence in the background variable' (e.g., Eeckhoudt et al., 2007; Baiardi et al., 2020).¹⁵ A zero-mean income risk in the destination country decreases the migration duration of migrant parents if they are cross-prudent in the child human capital ($U^{(2,1)} \geq 0$). The cross-derivative until order 2 in the wealth argument and until order 1 in the background variable $U^{(2,1)}$ is not new in the analysis of choice under risk. It was shown in the precautionary saving model, for example, that the sign of this third cross-derivative is part of the sufficient condition that determines precautionary saving, in a setting where the decision maker is faced, simultaneously, with a labor income risk and a background risk in the second period (see e.g., Courbage and Rey, 2007; Menegatti, 2009a,b; Denuit et al., 2011).¹⁶ In a context of temporary migration, the sign of $U^{(2,1)}$

¹⁵A background variable is defined as the second argument of the decision-maker's utility function, different from the monetary argument.

¹⁶While Courbage and Rey (2007) and Menegatti (2009a) report their results under specific assumptions on the joint distribution of an income risk and a background risk, Menegatti (2009b) and Denuit et al.

is the only condition needed in a setting where the decision maker is faced solely with a labor income risk, in the first period. Our setting is also different from that considered by Eeckhoudt et al. (2007) in a model of tertiary prevention. The sign of the cross-derivative until order 2 in the wealth argument and until order 1 in the background variable is the sufficient condition, in their model, for an increase in the investment in the tertiary prevention, under an income risk in the second period, rather than the first one.

In order to analyze our results, we refer to the interpretation of prudence provided by the precautionary saving literature. Following Menegatti (2007), condition $U^{(2,1)} \geq 0$ ensures that the disutility, suffered by the migrant parent because of the destination country's income risk, is reduced if the level of the child human capital is increased.¹⁷ This is done by decreasing the disinvestment in the child human capital, and thus, by decreasing the migration duration. Moreover, following Eeckhoudt and Schlesinger (2006), this effect can be explained by the migrant parent's preference to disaggregate the harm of a higher income risk and that of a lower child human capital.¹⁸

Risk on the home country income

The migrating parent is now faced with a future risk on his income at the country of origin ($y_2 + \tilde{\epsilon}_{2w}$). We investigate how this future income risk affects the optimal migration duration of the parent compared to a situation where there is no such risk, *ceteris paribus*. In other words, we investigate which among the two situations, where the parent uses migration to hedge against the future risk and where the parent uses migration for the sole purpose of increasing the future wealth, will induce a longer migration duration.

In the case of a future income risk in the country of origin, he maximizes the following lifetime utility

$$W_{\tilde{\epsilon}_{2w}}(m) = U(y_1, Z_1 - m) + \beta E[V(y_2 + \tilde{\epsilon}_{2w} + g(m), Z_2)]. \quad (1.5)$$

The optimal length of the parent's migration is denoted by $m_{\tilde{\epsilon}_{2w}}^*$. Following the same reasoning as previously, we obtain the following results.¹⁹

Proposition 3 *Under an unfavorable pure risk in the country of origin [second period],*

(2011) further highlight the role of this cross-derivative in determining precautionary saving, in the case of small risks, and where no assumption is made on risk distributions or on the size of risks, respectively.

¹⁷This disutility can be measured, following Menegatti (2007), by the difference between the expected utility when the migrant parent is bearing an income risk and the utility when there is no risk.

¹⁸Child human capital becomes more valuable in utility terms under risk if $U^{(2,1)} \geq 0$, i.e., remaining one additional unit of time in the destination country is more costly under the income risk compared to the situation with no risks: $E[U^{(0,1)}(y_1 + \tilde{\epsilon}_1, Z_1 - m^*)] \geq U^{(0,1)}(y_1, Z_1 - m^*)$, if $U^{(2,1)} \geq 0$.

¹⁹Proofs are omitted as they are analogous to the case of the destination country's risks, but are available upon request.

a migrant parent will stay longer (shorter) at destination than with no such risk, $m_{\tilde{\epsilon}_{2w}}^* \geq (\leq)m^*$, if $V^{(2,0)} \leq (\geq)0$.

Under a zero-mean risk on the country of origin's income [second period], a migrant parent will stay longer (shorter) at destination than with no such risk, $m_{\tilde{\epsilon}_{2w}}^* \geq (\leq)m^*$, if $V^{(3,0)} \geq (\leq)0$.

We show in Proposition 3 that an unemployment risk in the country of origin increases the migration duration of migrant parents only if they are risk averse ($V^{(2,0)} \leq 0$), i.e., they do not like the risk they will be facing if they return to the home country. The importance of risk aversion in the migration-decision-making has already been documented in the empirical literature (e.g., Jaeger et al., 2010; Dustmann et al., 2020).

We also show that the third-order derivative $V^{(3,0)}$ has a significant impact on determining the optimal migration duration, in the presence of a zero-mean income risk at the home country. $V^{(3,0)}$ refers to the feature of individuals' preference known as prudence, and particularly prudence in wealth (Kimball et al., 1990). In the saving literature, Leland (1978) was the first to show that the presence of a future risky income results in a positive extra saving if and only if the third-order derivative of the univariate utility function is positive. He called this additional amount of savings 'precautionary demand for saving' (see also, Sandmo, 1970; Dreze and Modigliani, 1975).²⁰ The role of prudence has also been shown in the health literature (see e.g., Brianti et al., 2018). In a migration context, we show that the zero-mean income risk increases the migration duration of parents only if they are prudent ($V^{(3,0)} \geq 0$), i.e., those for whom a higher level of wealth at the home country reduces the disutility induced by the income risk (Menegatti, 2007), and those for whom a combination of the harm from a higher income risk with a high level of wealth is preferred (Eeckhoudt and Schlesinger, 2006).^{21,22}

²⁰Even though, our model is different from that of the saving, we find the same condition for a precautionary behavior as the saving model (sign of $V^{(3,0)}$). This is because, similarly to the saving model, both the impact of the decision (here the increase of the home country's wealth) and the changes in risk are experienced at the same argument in the same period.

²¹Additional wealth at the home country becomes more valuable in utility terms under risk if $V^{(3,0)} \geq 0$, i.e., staying one extra unit of time at the destination country brings more benefits to the migrant parent under the income risk compared to the situation with no risks: $E[V^{(1,0)}(y_2 + \tilde{\epsilon}_{2w} + g(m^*), Z_2)] \geq V^{(1,0)}(y_2 + g(m^*), Z_2)$, if $V^{(3,0)} \geq 0$.

²²The case where migrant parents are faced with income risks simultaneously both in the home- and the destination countries is also possible. Migrant parents' behavior in terms of the migration duration, with respect to a situation with no risk, is independent of the correlation between the two risks. It depends only on the cross-prudence in child human capital and the prudence in wealth. Dustmann (1997), considering the migration of any individual that is faced with simultaneous income risks in the two countries, found that, in addition to the sign of the third order derivative of the utility function with respect to wealth (prudence), wage differentials and a comparison between the levels of risks between the two countries is needed to determine the variation of the migration duration with respect to a situation without risk.

1.3.2 Risk on the child human capital

Children can also be faced with an exogenous risk on their human capital, and since parents care about the human capital of their children, their migration behavior can, as a consequence, be affected. This risk can be related to different factors, with air pollution being one example. 93% of children worldwide were exposed to levels of air pollution above the World Health Organization guidelines, in 2016 (Organization, 2018). This air pollution may affect the child human capital through its effect on child health, schooling and cognitive functioning (see e.g., Currie et al., 2014). In our model, we particularly focus on pollutants that induce harm following a prolonged exposure (over months or even years), and therefore, we introduce a risk on child human capital only in the second-period.

The migrating parent is now faced with a future risk on his child's human capital ($Z_2 + \tilde{\epsilon}_{2z}$). We investigate, therefore, how the future child human capital risk affects the optimal migration duration of the parent with respect to a situation where there is no such risk, *ceteris paribus*.

In the case of no risks, the parent's maximization problem is given by Eq. (1.1). In the case of a risk on his child's human capital, he maximizes the following lifetime utility

$$W_{\tilde{\epsilon}_{2z}}(m) = U(y_1, Z_1 - m) + \beta E[V(y_2 + g(m), Z_2 + \tilde{\epsilon}_{2z})] \quad (1.6)$$

We denote by $m_{\tilde{\epsilon}_{2z}}^*$ the length of the parent's migration in this case. Applying the same reasoning as before, we get the following proposition.

Proposition 4 *Under a pure risk on his child's human capital upon his return to the home country [second period], a migrant parent will stay longer (shorter) at destination than with no such risk, $m_{\tilde{\epsilon}_{2z}}^* \geq (\leq) m^*$, if $V^{(1,1)} \geq (\leq) 0$.*

Under a zero-mean risk on his child's human capital upon his return to the home country [second period], a migrant parent will stay longer (shorter) at destination than with no such risk, $m_{\tilde{\epsilon}_{2z}}^ \geq (\leq) m^*$, if $V^{(1,2)} \geq (\leq) 0$.*

We show that, following a pure risk on the child's human capital, migrant parents will increase the duration of their migration only if they are correlation averse, i.e., those for whom a higher child human capital level increases their marginal utility of income.

We also show that the sign of the effect of a zero-mean child human capital risk on the migration duration of parents depends on the sign of the third cross-derivative $V^{(1,2)}$, which we refer to as 'cross-prudence in wealth'. In the classic saving problem,

Eeckhoudt et al. (2007) showed that, under a future risk on the background variable (health), precautionary saving is positive whenever $V^{(1,2)}$ is positive, i.e., whenever the decision maker is ‘cross-prudent in wealth’. Baiardi et al. (2014) also reported a complex condition depending, among other elements, on $V^{(1,2)}$, but when considering a background risk flanked by a labor income risk and an interest rate risk. Similarly, in a model of health investment, comparing a situation with simultaneous income and background risks to a situation with only an income risk, Denuit et al. (2011) found that the sufficient condition for a precautionary health investment depends, among other elements, on $V^{(1,2)}$.²³ In our analysis of migration duration decision under a child human capital risk, we find that the migration duration of parents increases only if they are cross-prudent in wealth, i.e., those for whom a higher level of wealth at the country of origin reduces the disutility, suffered because of the risk on the child human capital (Menegatti, 2007), and those that would prefer to face the child human capital risk when it is coupled with a higher wealth (Eeckhoudt and Schlesinger, 2006).²⁴

1.3.3 Risk on the migrant’s accumulated savings

In addition to income risks at the destination and the origin countries, the accumulated savings generated from working at the destination country that the migrant parent wants to bring home may also become risky. An example is the major and unexpected interest rate or exchange rate fluctuations that may change the potential values of these savings in the country of origin, making them risky.

Now, the migrant’s accumulated savings are risky, $\tilde{g}(m)$. We investigate how the riskiness of the parent’s savings affects the duration of migration with respect to a situation with no risks, *ceteris paribus*. Previously, we considered that income risks are additive in nature, in the sense that they affect the parent independently from his income levels. The assumption of additive risks, in this section, would yield results that are technically identical to the case of introducing a risk on the home country’s income, given by proposition 3. We consider, therefore, the multiplicative form of the risk such that $\tilde{g}(m) = g(m)\tilde{\eta}$, where $E(\tilde{\eta}) = 1$, in the sense that risk is proportional to the migration duration of the parent.²⁵

²³Menegatti (2009b) and Denuit et al. (2011) show that, comparing a situation with a simultaneous income and background risks to a situation with no risks, the sufficient condition for a precautionary saving depends, among other elements, on both of the cross-derivatives $V^{(1,2)}$ and $V^{(2,1)}$.

²⁴Remaining one additional unit of time in the destination country brings more benefits under the child human capital risk compared to the situation with no risks: $E[V^{(1,0)}(y_2 + g(m^*), Z_2 + \tilde{\epsilon}_{2z})] \geq V^{(1,0)}(y_2 + g(m^*), Z_2)$, if $V^{(1,2)} \geq 0$.

²⁵Realizations of the random variable $\tilde{\eta}$ are assumed to be all positive to ensure that the accumulated

For the sake of simplicity, we assume that $y_2 = 0$. The parent maximizes the following lifetime utility

$$W_{\tilde{\eta}}(m) = U(y_1, Z_1 - m) + \beta E[V(g(m)\tilde{\eta}, Z_2)]. \quad (1.7)$$

We denote by $m_{\tilde{\eta}}^*$ the length of the migration, had the parent chosen to go to destination D_2 , implying a FOC given by

$$W'_{\tilde{\eta}}(m_{\tilde{\eta}}^*) = -U^{(0,1)}(y_1, Z_1 - m_{\tilde{\eta}}^*) + \beta E[g'(m_{\tilde{\eta}}^*)\tilde{\eta}V^{(1,0)}(g(m_{\tilde{\eta}}^*)\tilde{\eta}, Z_2)] = 0 \quad (1.8)$$

In order to analyze the effects of a stochastic saving level on optimal migration duration we compare (1.8) with (1.2). We obtain the following result.

Proposition 5 *A migrant parent will stay longer (shorter) at a destination where his accumulated savings are risky than at a destination where they are not, $m_{\tilde{\eta}}^* \geq (\leq) m^*$, if $-g(m)\eta \frac{V^{(3,0)}(y,Z)}{V^{(2,0)}(y,Z)} \geq (\leq) 2$.*

Proof See Appendix 1.C.

The above proposition shows that when the accumulated savings of the migrant parent at the country of destination are risky, a threshold level of 2 for $-g(m^*)\eta \frac{V^{(3,0)}}{V^{(2,0)}}$ determines whether the migrant increases or decreases the length of migration, with respect to the duration of migration in a similar destination with no such risk. $-g(m^*)\eta \frac{V^{(3,0)}}{V^{(2,0)}}$ is a relative prudence index.²⁶ A risk on the accumulated savings of the migrant parent would increase his migration duration only if he has a relative prudence larger than 2, i.e., if his prudence is sufficiently “stronger” than his risk aversion. In fact, under prudence ($V^{(3,0)} \geq 0$), a migrant parent would prefer to have a higher wealth when he faces a risk, and thus would have an incentive to increase the migration duration, in order to increase the expected accumulated savings. However, when one increases the migration duration, one is receiving proportionally more risk. As the migrant parent is supposed to be risk averse ($V^{(2,0)} \leq 0$), he does not like this second effect, and thus, would have an incentive to reduce the migration duration. Therefore, the overall impact depends on which of the above effects dominates. Previous work on the choice under risk indicated, indeed, that risk on returns is related to a condition of relative prudence. In the saving literature,

savings brought to the home country are always positive. In case where the realization of $\tilde{\eta}$ is η , such that $0 < \eta < 1$ ($\eta = 1$, $\eta > 1$), the accumulated savings are lower (equal to, bigger) than that under certainty.

²⁶Following Kimball et al. (1990), we define, for a bivariate function $G(y, Z)$, absolute prudence as $-\frac{G^{(3)}(y,Z)}{G^{(2)}(y,Z)}$ and relative prudence as $-y \frac{G^{(3)}(y,Z)}{G^{(2)}(y,Z)}$. Note that if the second-period income was not zero, then results would involve “partial relative prudence” instead of “relative prudence” (see Chiu et al., 2012).

the index of relative prudence being larger than 2 would be required for precautionary saving to occur when the interest rate (the return of saving) is risky (e.g., Rothschild and Stiglitz, 1971; Eeckhoudt and Schlesinger, 2008). A similar condition has been found to control the decision maker’s behavior when a return on a health investment is risky (Liu and Menegatti, 2019b).²⁷

1.4 Increase in risks

In the previous section, we investigated the effects of the introduction of some kind of risks on the migration duration decision process compared to a situation with no risks. Now, we generalize our results to the case where migrants may move from a risky unemployment situation to an even riskier one. Moreover, the situations in Section 1.3 imply only changes in the variables’ variance and/or expectation. We consider, therefore, other cases of increases in risk (comparing two risky situations) that imply changes in the variables’ distributions’ other higher-order moments. We do so using the concept of n th-order stochastic dominance. The later is concerned with the comparison of probability distributions of random variables that have different moments of higher order. The particular case of Ekern’s (1980) concept of increase in n th-degree risk is also considered.²⁸

1.4.1 Increases in income risks

Consider the case where the parent has the option to migrate to two similar destinations D_1 and D_2 , where the earnings are risky, but that in D_2 ($y_1 + \tilde{\theta}_{1w}$) are riskier than that in D_1 ($y_1 + \tilde{\epsilon}_{1w}$) in terms of n th-order stochastic dominance ($\tilde{\theta}_{1w} \preceq_{SD-n} \tilde{\epsilon}_{1w}$). We investigate how the level of increase in income risk at the destination country affects the migration duration of the parent, *ceteris paribus*.

In the case where the parent considers migrating to destination D_1 , his maximization problem is given by Eq. (1.3). In the case where he considers migrating to destination D_2 , he maximizes the following lifetime utility

$$W_{\tilde{\theta}_{1w}}(m) = E[U(y_1 + \tilde{\theta}_{1w}, Z_1 - m)] + \beta V(y_2 + g(m), Z_2). \quad (1.9)$$

²⁷Note that our results are sensitive to the migrant’s utility functional form. The later allows to derive more particular conditions for the effects, on the migration duration, of income, child human capital and the different risks considered in this paper.

²⁸See appendix 1.E for more details about the n th-order stochastic dominance and Ekern’s (1980) concept of increase in n th-degree risk.

We denote by $m_{\tilde{\theta}_{1w}}^*$ the optimal migration duration, in this case, implying a FOC given by

$$W'_{\tilde{\theta}_{1w}}(m_{\tilde{\theta}_{1w}}^*) = -E[U^{(0,1)}(y_1 + \tilde{\theta}_{1w}, Z_1 - m_{\tilde{\theta}_{1w}}^*)] + \beta g'(m_{\tilde{\theta}_{1w}}^*) V^{(1,0)}(y_2 + g(m_{\tilde{\theta}_{1w}}^*), Z_2) = 0. \quad (1.10)$$

Comparing (1.10) and (1.4), we obtain the following result.

Proposition 6 *A migrant parent will stay longer (shorter) in destination D_2 where his earnings are riskier, in terms of n th-order stochastic dominance, than in destination D_1 , $m_{\tilde{\theta}_{1w}}^* \geq (\leq) m_{\tilde{\epsilon}_{1w}}^*$, if his preferences are such that $(1)^{(1+k)}U^{(k,1)} \geq (\leq) 0 \forall k = 1, \dots, n$.*

Proof See Appendix 1.F.

Proposition 6 shows that changes in the migration duration of parents, following increases in the destination country's income risk, require conditions on the parents' preferences that involve the sign of higher-order derivatives of their utility function. This result is typical when considering increases in risk in terms of n th-order stochastic dominance. In particular, these conditions were first provided by Eeckhoudt and Schlesinger (2008), in the case of a univariate utility function. This work was generalized by Chiu and Eeckhoudt (2010) in the case of a bivariate utility, considering decisions on labor supply.

If we restrict changes in the destination's income risk to the special case defined by Ekern (1980), then a migrant parent, facing a n th-degree riskier income at destination D_2 than in destination D_1 , will stay longer (shorter) at destination D_2 , if his preferences are such that $(1)^{(1+n)}U^{(n,1)} \geq (\leq) 0$. This result provides, therefore, a generalization of the migrant parent's behavior under a zero-mean risk, shown in proposition 2. The later considers the particular case of second-order increase in risk ($n=2$).

Consider now two migrant parents (referred to as A and B) that are similar in their characteristics but differ in the level of the income risk in their country of origin. The home country's income for migrant B ($y_2 + \tilde{\theta}_{2w}$) is riskier than that for migrant A ($y_2 + \tilde{\epsilon}_{2w}$) in terms of n th-order stochastic dominance ($\tilde{\theta}_{2w} \preceq_{SD-n} \tilde{\epsilon}_{2w}$). We investigate how the level of increase in income risk at the home country affects the duration of migration, ceteris paribus.

The maximization problem of the migrant parent A is given by Eq. (1.5), while migrant parent B maximizes the following lifetime utility

$$W_{\tilde{\theta}_{2w}}(m) = U(y_1, Z_1 - m) + \beta E[V(y_2 + \tilde{\theta}_{2w} + g(m), Z_2)]. \quad (1.11)$$

We denote by $m_{\tilde{\theta}_{2w}}^*$ the optimal migration duration of migrant B. Following a similar

reasoning as previously, we get the following proposition.

Proposition 7 *Migrant parent B, facing, at the country of origin, a riskier income, in terms of n th-order stochastic dominance, compared to a similar migrant parent A, will stay longer (shorter) at destination, $m_{\tilde{\theta}_{2w}}^* \geq (\leq) m_{\tilde{\epsilon}_{2w}}^*$, if his preferences are such that $(1)^{(1+k)}V^{(k+1,0)} \leq (\geq) 0 \forall k = 1, \dots, n$.*

If we restrict changes in the country of origin's income risk to the special case defined by Ekern (1980), then a migrant parent B, facing a n th-degree riskier income at the country of origin compared to migrant parent A, will stay longer (shorter) at destination, if his preferences are such that $(1)^{(1+n)}V^{(n+1,0)} \leq (\geq) 0$. The special case of introducing a zero-mean income risk in the country of origin is a second-order increase in risk ($n=2$), and the migration behavior is given by proposition 3.

1.4.2 Increases in the risk on the child human capital

Consider two parents (referred to as A and B). The two parents and their respective children are similar in their characteristics but differ in the level of the risk their children are exposed to. The human capital of migrant B's child ($Z_2 + \tilde{\theta}_{2z}$) is riskier than that of migrant A's child ($Z_2 + \tilde{\epsilon}_{2z}$) in terms of n th-order stochastic dominance ($\tilde{\theta}_{2z} \preceq_{SD-n} \tilde{\epsilon}_{2z}$). We investigate how the level of increase in child human capital risk affects the duration of migration, ceteris paribus.

The maximization problem of the migrant parent A is given by Eq. (1.6), while migrant parent B maximizes the following lifetime utility

$$W_{\tilde{\theta}_{2z}}(m) = U(y_1, Z_1 - m) + \beta E[V(y_2 + g(m), Z_2 + \tilde{\theta}_{2z})]. \quad (1.12)$$

We denote by $m_{\tilde{\theta}_{2z}}^*$ the optimal migration duration of migrant B. Following a similar reasoning as previously, we get the following proposition.

Proposition 8 *Migrant parent B, facing a riskier human capital of his child, in terms of n th-order stochastic dominance, compared to migrant parent A, will stay longer (shorter) at destination, $m_{\tilde{\theta}_{2z}}^* \geq (\leq) m_{\tilde{\epsilon}_{2z}}^*$, if his preferences are such that $(1)^{(1+k)}V^{(1,k)} \leq (\geq) 0 \forall k = 1, \dots, n$.*

If we restrict changes in the child human capital risk to the special case defined by Ekern (1980), then a migrant parent B, facing a n th-degree riskier human capital of his child compared to migrant parent A, will stay longer (shorter) at destination, if his

preferences are such that $(1)^{(1+n)}V^{(1,n)} \leq (\geq)0$. Proposition 4 is the particular case of this result when $n=2$.

1.4.3 Increases in risk on the accumulated savings

Consider a parent that has the option to migrate to two similar destinations D_1 and D_2 , but where the accumulated savings of the migrant parent in D_2 ($g(m)\tilde{\zeta}$) would be riskier than that in D_1 ($g(m)\tilde{\eta}$), in terms of n th-order stochastic dominance ($\tilde{\zeta} \preceq_{SD-n} \tilde{\eta}$). We investigate how the level of increase in the riskiness on the savings accumulated during the work at the destination country affects the duration of migration, ceteris paribus.

In the case where the parent considers migrating to destination D_1 , his maximization problem is given by Eq. (1.7). In the case where the parent considers migrating to destination D_2 , he maximizes the following lifetime utility

$$W_{\tilde{\zeta}}(m) = U(y_1, Z_1 - m) + \beta E[V(g(m)\tilde{\zeta}, Z_2)] \quad (1.13)$$

We denote by $m_{\tilde{\zeta}}^*$ the length of the migration, had the parent chosen to migrate to destination D_2 . The FOC of this problem is given by

$$W'_{\tilde{\zeta}}(m_{\tilde{\zeta}}^*) = -U^{(0,1)}(y_1, Z_1 - m_{\tilde{\zeta}}^*) + \beta E[g'(m_{\tilde{\zeta}}^*)\tilde{\zeta}V^{(1,0)}(g(m_{\tilde{\zeta}}^*)\tilde{\zeta}, Z_2)] = 0. \quad (1.14)$$

Assuming that $\eta g(m_{\tilde{\eta}}) = y$, where $y > 0$, and comparing (1.14) and (1.8), we obtain the following result.

Proposition 9 *A migrant parent will stay longer (shorter) in destination D_2 , where his accumulated savings are riskier, in terms of n th-order stochastic dominance, than in destination D_1 , $m_{\tilde{\zeta}}^* \geq (\leq)m_{\tilde{\eta}}^*$, if his preferences are such that $-y \frac{V^{(k+1,0)}}{V^{(k,0)}} \geq (\leq)k \forall (y, Z)$, $\forall k = 1, \dots, n$.*

Proof See Appendix 1.G.

Proposition 9 shows that the change in the optimal migration duration is governed by the value of the n -th degree relative risk aversion.²⁹

If we restrict changes in the accumulated savings risk to the special case defined by Ekern (1980), then a migrant parent facing a n th-degree riskier accumulated savings at destination D_2 than at destination D_1 will stay longer (shorter) at destination D_2 if his

²⁹Note that if the income at the country of origin was not assumed zero, the results would involve a “partial n -th degree risk aversion” measure instead of a “relative n -th degree risk aversion” measure (see, Chiu et al., 2012).

preferences are such that $-y \frac{V^{(n+1,0)}}{V^{(n,0)}} \geq (\leq)n$. Proposition 5 is the particular case of this result when $n = 2$.

1.5 Theoretical results versus empirical applications

In the previous section, we have shown how increases in risk imply different effects on the migration duration of parents. In order to incorporate our analysis into the empirical literature, we show how different measures of risk reflect different orders of risk changes and require different conditions to explain parental migration behavior.

In the empirical literature of migration, the increase in the home country's income risk has been measured by the variance of the residuals of the income regression (Jalan and Ravallion, 2001), the coefficient of variation of income (Munshi and Rosenzweig, 2016), and the coefficient of variation of temperature or rainfall variance (Rosenzweig and Stark, 1989; Dillon et al., 2011). When the income is normally distributed, the increase in its variance is sufficient to guarantee an increase in the second-order risk.³⁰ All risk averse migrant parents, i.e., those with a marginal utility that is decreasing with wealth, should dislike such changes in the distribution of their incomes. However, a change in the migration duration is not guaranteed unless the migrants exhibit a specific preference known as prudence. Munshi and Rosenzweig (2016) and Jalan and Ravallion (2001) found that greater rural income risk inhibits rural-urban migration in India and China, respectively, while Dillon et al. (2011) and Rosenzweig and Stark (1989) found evidence of an increased probability of migration due to the agricultural income risk in northern Nigeria and rural India, respectively. These studies suggest evidence for precautionary changes in the migration likelihood. If changes in the migration probability are similar to that in the migration duration, in the face of income risk, our results suggest that a sufficient condition for these behaviors is the sign of prudence.

The implementation of the labor market reform, *Hartz IV*, in January 2005, in Germany, typically generated a first-order increase in labor income risk, as it significantly decreased the generosity and toughened the eligibility requirements of unemployment benefits. Applying our results, the expected effect on migration spells, for foreign migrant parents in Germany, is an increase in the migration duration if they are correlation loving, *ceteris paribus*. While, for German parents abroad, such a reform would increase their migration duration at the destination if they are risk averse, *ceteris paribus*.³¹

³⁰This is true for any symmetric distribution of the income.

³¹Covid-19 pandemic has also been shown to increase the probability of unemployment in a number of countries (Dang and Nguyen, 2021). Increases in unemployment would result in changes in the migration

During the 2000s, tax reforms in favor of flat personal income tax structures have been adopted in a number of countries, including Iceland in 2007 and Czech Republic in 2008. Davies and Hoy (2002) show how moving from an income tax with a graduated rate tax schedule (progressive tax schedule) to one with a single marginal rate levied on the same base (flat tax scheme) and a personal allowance adjusted to generate the same tax yield under the two tax schemes, may induce a decrease in the level of third-order risk within the after-tax income distribution.³² A tax flattening exercise will result in a mean preserving contraction at the lower level of the income distribution (a progressive transfer) and a mean preserving spread (a regressive transfer). If the two tax schedules maintain the same tax yield for the government, the mean is unchanged between the two post-tax income distributions. If their variance is also kept unchanged, then tax flattening parallels a decrease in downside risk as defined by Menezes et al. (1980).³³ Migrant parents exhibiting prudence like this decrease in downside risk. However, a change in the migration duration is not guaranteed unless migrant parents exhibit a specific preference known as temperance. Foreign migrant parents in Czech Republic, for example, may stay longer in the country after the tax flattening reform if they are cross-temperate (i.e., if $U^{(3,1)} \leq 0$), ceteris paribus. On the other hand, Czech migrant parents may stay shorter at any destination after their country's tax reform if they are temperate in wealth (i.e., if $V^{(4,0)} \leq 0$), ceteris paribus.

Furthermore, economic news were found to affect the first moment of the short- and medium term interest rates in the United States (e.g., Tuysuz and Lubochinsky, 2019) and that of the exchange rates (e.g., Jansen and De Haan, 2005). This might indicate that, following certain news announcements, interest and exchange rates are expected to be stochastically lower, i.e., their conditional distributions would deteriorate in the sense of first-order stochastic dominance. In this case, foreign migrant parents in the United States should stay longer, even if they are now faced with a more unfavourable situation in terms of stochastic dominance, if their relative risk aversion exceeds 1 (i.e., if $-y \frac{V^{(2,0)}}{V^{(1,0)}} \geq 1$), ceteris paribus.

Finally, financial integration, in the sense that banks in different countries are able to

duration of migrant parents similar to that provoked by decreases in the unemployment payments.

³²Chiu (2010) also showed that the after-tax income distribution under a flat tax schedule is more skewed to the right (third moment of the after-tax income distribution is higher) than that under a graduated-rate tax schedule. This suggests that the tax-flattening may decrease the downside income risk.

³³Even though, the immediate effects are observed as a redistribution of wealth within the population, the results can be transferred in terms of earning probabilities. For a given worker, the possible incomes under the flat tax schedule are higher, but with higher probabilities for the lower possible incomes and lower probabilities for the higher possible incomes, than under the progressive tax schedule.

smooth local liquidity shocks by borrowing on the world interbank market, is shown to increase skewness of the interest rate distribution (e.g., Castiglionesi et al., 2019). As an increase in skewness may reflect a third-degree decrease in risk, migrant parents may stay shorter at the destination where the financial integration took place if they are relative temperate (i.e., if $-y \frac{v^{(4,0)}}{v^{(3,0)}} \geq 3$).

1.6 Conclusion

In this paper, we develop a simple model where migrant parents, with children left behind in the home country, determine their optimal migration duration. We focus on examining the effects of different risks on the desired length of stay at the destination country, compared to a situation with no risks. Then, we generalize our analysis to comparing decisions under different levels of the same risk. Based on the equivalence between the decreases in the child human capital and the length of the parental migration, our model produces a number of interesting and new results.

First, we show that, in the absence of risks, larger income differentials between home- and destination countries may decrease the optimal migration duration. As a consequence, if the inflow of migrants is regulated, a growing economic disparity between the two countries may result in a lower stock of migrants in the destination country, at any point in time. We show that such a behavior can be explained by the parental correlation attitude.

Second, we show that the effect of the introduction of an unemployment risk in the home- or the destination country on the migration duration can be explained by risk aversion or correlation aversion of the migrating parent, respectively. However, risk aversion alone is not a sufficient condition for a precautionary behavior, in a context that introduces a zero-mean income risk. We show the need, in the later context, for either prudence or cross-prudence, i.e., a risk preference of order three, to ensure an increase in the optimal migration duration. In the case where the migrant's accumulated savings from work at the destination country become risky, our analysis shows the existence of incentives of opposite directions, referred to as relative prudence, to adjust the optimal migration duration. The later increases only if risk aversion is sufficiently "weaker" for parents than prudence. Considering a risk on the left-behind child's future human capital, cross-prudence is found to be the condition required for the migrant parent to change the duration of his migration abroad.

We, further, show how our results can be generalized to the case of changes in risk of

order N , as defined by Ekern (1980). In this case, the role of risk preferences of higher order in determining the variation of the optimal migration duration is shown. One consequence of our results is that increases in income risks in the destination country or decreases in income risks in the home country may lead to longer migration cycles, and to an increase in the size of the migrant population at the destination country, as long as the inflow of migrants is kept constant (and vice versa).

Our results also suggest a number of implications. First, understanding the amount and characteristics of risks that are faced by migrant parents in the home- or the destination country may, in part, help policy makers with tools to control temporary migration, if coupled with information on the risk preferences of migrant parents.

Second, our findings suggest that the presence of risks leads to a self-selection of migrants with respect to their risk preferences, in terms of who stays longer and who returns faster. As some economically important attributes vary with the degree of these preferences, their distribution among migrants would matter. Indeed, it was shown that higher levels of prudence are correlated with better education and higher cognitive ability (Noussair et al., 2014; Breaban et al., 2016). While other studies found that risk aversion is negatively, even if only weakly, related to cognitive ability (Lilleholt, 2019) and hinders entrepreneurship (Cramer et al., 2002; Zhang and Cain, 2017). Our results on selectivity predict that, under increases in unemployment risk in the country of origin, foreign labor market is more likely to keep, for a longer period, a labor force with a possibly lower cognitive ability and lower entrepreneurship intentions, *ceteris paribus*. However, under increases in income risks, that imply changes in the income's distribution's variance, in the home country, foreign labor market is more likely to benefit longer from a labor supply, among the risk averse migrant parents, that has better education and cognitive abilities, *ceteris paribus*. It appears, therefore, that, it is crucial to control for risk preferences, other than risk aversion, in empirical migration studies, in order to net out the effect of the varying levels of these preferences with other personal characteristics. The development of approaches used to measure these preferences makes it easier to collect such data in administrative surveys.

Finally, conditions governing the parents' migration duration, following increases in income differentials or in the different income and child human capital risks, involve preferences carrying cross-effects between the income and children's human capital, which themselves are affected by the parental utility functional form. Hence, the importance of these features in the selection of models describing migrant parents' preferences and for future empirical work.

Different developments can be suggested for future research. Our analysis considers the effect of risk on migration behavior under the assumption that the migration duration decision is made in isolation. However, that decision can be simultaneously taken with some other choices such as the monetary investment in the human capital of the child. Another extension is considering the case where the migrant parent does not necessarily know the objective probabilities of a future event that may affect his decision, and does not even have a clear subjective opinion on them. This uncertainty is referred to as ‘ambiguity’ and the preference of a migrant that wants to avoid such situation is called ‘ambiguity aversion’ (Klibanoff et al., 2005).

Bibliography

- Antman, F. M. (2013). The impact of migration on family left behind. In *International handbook on the economics of migration*. Edward Elgar Publishing.
- Attanasio, O. P. (2015). The determinants of human capital formation during the early years of life: Theory, measurement, and policies. *Journal of the European Economic Association*, 13(6):949–997.
- Baiardi, D., Magnani, M., and Menegatti, M. (2014). Precautionary saving under many risks. *Journal of Economics*, 113(3):211–228.
- Baiardi, D., Magnani, M., and Menegatti, M. (2020). The theory of precautionary saving: an overview of recent developments. *Review of Economics of the Household*, 18(2):513–542.
- Becker, G. S., Kominers, S. D., Murphy, K. M., and Spenkuch, J. L. (2018). A theory of intergenerational mobility. *Journal of Political Economy*, 126(S1):S7–S25.
- Beenstock, M., Chiswick, B. R., and Paltiel, A. (2010). Testing the immigrant assimilation hypothesis with longitudinal data. *Review of Economics of the Household*, 8(1):7–27.
- Berlingieri, G., Blanchenay, P., and Criscuolo, C. (2017). The great divergence (s).
- Bleichrodt, H., Crainich, D., and Eeckhoudt, L. (2003). Comorbidities and the willingness to pay for health improvements. *Journal of Public Economics*, 87(11):2399–2406.
- Breaban, A., Van De Kuilen, G., and Noussair, C. N. (2016). Prudence, emotional state, personality, and cognitive ability. *Frontiers in psychology*, 7:1688.
- Brianti, M., Magnani, M., and Menegatti, M. (2018). Optimal choice of prevention and cure under uncertainty on disease effect and cure effectiveness. *Research in Economics*, 72(2):327–342.
- Carrington, W. J., Detragiache, E., and Vishwanath, T. (1996). Migration with endogenous moving costs. *The American Economic Review*, pages 909–930.
- Castiglionesi, F., Feriozzi, F., and Lorenzoni, G. (2019). Financial integration and liquidity crises. *Management Science*, 65(3):955–975.
- Chan, A. (2005). Recent trends in Chinese labour issues—signs of change. *China Perspectives*, 2005(57).
- Chen, K.-P., Chiang, S.-H., and Leung, S. F. (2003). Migration, family, and risk diversification. *Journal of Labor Economics*, 21(2):353–380.
- Cheng, J. and Sun, Y.-H. (2015). Depression and anxiety among left-behind children in china: a systematic review. *Child: care, health and development*, 41(4):515–523.

- Chiu, W. H. (2010). Skewness preference, risk taking and expected utility maximisation. *The Geneva Risk and Insurance Review*, 35(2):108–129.
- Chiu, W. H. and Eeckhoudt, L. (2010). The effects of stochastic wages and non-labor income on labor supply: update and extensions. *Journal of Economics*, 100(1):69–83.
- Chiu, W. H., Eeckhoudt, L., and Rey, B. (2012). On relative and partial risk attitudes: theory and implications. *Economic Theory*, 50(1):151–167.
- Cortes, P. (2015). The feminization of international migration and its effects on the children left behind: Evidence from the philippines. *World Development*, 65:62–78.
- Courbage, C. and Rey, B. (2007). Precautionary saving in the presence of other risks. *Economic Theory*, 32(2):417–424.
- Crainich, D., Eeckhoudt, L., and Le Courtois, O. (2017). Health and portfolio choices: A diffidence approach. *European Journal of Operational Research*, 259(1):273–279.
- Cramer, J. S., Hartog, J., Jonker, N., and Van Praag, C. M. (2002). Low risk aversion encourages the choice for entrepreneurship: an empirical test of a truism. *Journal of economic behavior & organization*, 48(1):29–36.
- Currie, J., Zivin, J. G., Mullins, J., and Neidell, M. (2014). What do we know about short-and long-term effects of early-life exposure to pollution? *Annu. Rev. Resour. Econ.*, 6(1):217–247.
- Dang, H.-A. H. and Nguyen, C. V. (2021). Gender inequality during the covid-19 pandemic: Income, expenditure, savings, and job loss. *World Development*, 140:105296.
- Daveri, F. and Faini, R. (1999). Where do migrants go? *Oxford Economic Papers*, 51(4):595–622.
- Davies, J. B. and Hoy, M. (2002). Flat rate taxes and inequality measurement. *Journal of Public Economics*, 84(1):33–46.
- Denuit, M. M., Eeckhoudt, L., and Menegatti, M. (2011). Correlated risks, bivariate utility and optimal choices. *Economic Theory*, 46(1):39–54.
- Dillon, A., Mueller, V., and Salau, S. (2011). Migratory responses to agricultural risk in northern nigeria. *American Journal of Agricultural Economics*, 93(4):1048–1061.
- Djajić, S. and Milbourne, R. (1988). A general equilibrium model of guest-worker migration: The source-country perspective. *Journal of international economics*, 25(3-4):335–351.
- Dreze, J. H. and Modigliani, F. (1975). Consumption decisions under uncertainty. In *Stochastic Optimization Models in Finance*, pages 459–486. Elsevier.
- Dustmann, C. (1993). Earnings adjustment of temporary migrants. *Journal of Population Economics*, 6(2):153–168.
- Dustmann, C. (1995). Savings behavior of return migrants. *Zeitschrift fuer Wirtschafts- und Sozialwissenschaften*, 115:511–533.
- Dustmann, C. (1997). Return migration, uncertainty and precautionary savings. *Journal of Development Economics*, 52(2):295–316.

- Dustmann, C. (1999). Temporary migration, human capital, and language fluency of migrants. *scandinavian Journal of Economics*, 101(2):297–314.
- Dustmann, C. (2003a). Children and return migration. *Journal of population economics*, 16(4):815–830.
- Dustmann, C. (2003b). Return migration, wage differentials, and the optimal migration duration. *European Economic Review*, 47(2):353–369.
- Dustmann, C., Fasani, F., Meng, X., and Minale, L. (2020). Risk attitudes and household migration decisions. *Journal of Human Resources*, pages 1019–10513R1.
- Dustmann, C. and Görlach, J.-S. (2016). The economics of temporary migrations. *Journal of Economic Literature*, 54(1):98–136.
- Dustmann, C. and Kirchkamp, O. (2002). The optimal migration duration and activity choice after re-migration. *Journal of Development Economics*, 67(2):351–372.
- Eeckhoudt, L., Rey, B., and Schlesinger, H. (2007). A good sign for multivariate risk taking. *Management Science*, 53(1):117–124.
- Eeckhoudt, L. and Schlesinger, H. (2006). Putting risk in its proper place. *American Economic Review*, 96(1):280–289.
- Eeckhoudt, L. and Schlesinger, H. (2008). Changes in risk and the demand for saving. *Journal of Monetary Economics*, 55(7):1329–1336.
- Ekern, S. (1980). Increasing nth degree risk. *Economics Letters*, 6(4):329–333.
- Epstein, L. G. and Tanny, S. M. (1980). Increasing generalized correlation: a definition and some economic consequences. *Canadian Journal of Economics*, pages 16–34.
- Fellmeth, G., Rose-Clarke, K., Zhao, C., Busert, L. K., Zheng, Y., Massazza, A., Sonmez, H., Eder, B., Blewitt, A., Lertgrai, W., et al. (2018). Health impacts of parental migration on left-behind children and adolescents: a systematic review and meta-analysis. *The Lancet*, 392(10164):2567–2582.
- Galor, O. and Stark, O. (1991). The probability of return migration, migrants’ work effort, and migrants’ performance. *Journal of development economics*, 35(2):399–405.
- Ingersoll, J. E. (1987). *Theory of financial decision making*, volume 3. Rowman & Littlefield.
- International Organization for Migration (IOM) (2020). *World Migration Report 2020*. Available at <https://publications.iom.int/books/world-migration-report-2020>.
- Jaeger, D. A., Dohmen, T., Falk, A., Huffman, D., Sunde, U., and Bonin, H. (2010). Direct evidence on risk attitudes and migration. *The Review of Economics and Statistics*, 92(3):684–689.
- Jalan, J. and Ravallion, M. (2001). Behavioral responses to risk in rural china. *Journal of Development Economics*, 66(1):23–49.
- Jansen, D.-J. and De Haan, J. (2005). Talking heads: the effects of ecb statements on the euro–dollar exchange rate. *Journal of International Money and Finance*, 24(2):343–361.

- Katz, E. and Stark, O. (1986). Labor migration and risk aversion in less developed countries. *Journal of Labor Economics*, 4(1):134–149.
- Kimball, M. (1992). Precautionary motives for holding assets. In Newman, P., Milgate, M., and Falwell, J. E., editors, *The New Palgrave Dictionary of Money and Finance*. MacMillan, London.
- Kimball, M. S. et al. (1990). Precautionary saving in the small and in the large. *Econometrica*, 58(1):53–73.
- Klibanoff, P., Marinacci, M., and Mukerji, S. (2005). A smooth model of decision making under ambiguity. *Econometrica*, 73(6):1849–1892.
- Leland, H. E. (1978). Saving and uncertainty: The precautionary demand for saving. In *Uncertainty in economics*, pages 127–139. Elsevier.
- Lilleholt, L. (2019). Cognitive ability and risk aversion: A systematic review and meta analysis. *Judgment & Decision Making*, 14(3).
- Liu, D. and Menegatti, M. (2019a). Optimal saving and health prevention. *Journal of Economics*, 128(2):177–191.
- Liu, D. and Menegatti, M. (2019b). Precautionary investment in wealth and health. *Journal of Risk and Insurance*, 86(1):237–255.
- Man, X., Barth, R. P., Li, Y.-e., and Wang, Z. (2017). Exploring the new child protection system in mainland china: How does it work? *Children and Youth Services Review*, 76:196–202.
- Menegatti, M. (2007). A new interpretation for the precautionary saving motive: a note. *Journal of Economics*, 92(3):275–280.
- Menegatti, M. (2009a). 20090530precautionary saving in the presence of other risks: a comment. *Economic Theory*, 39(3):473–476.
- Menegatti, M. (2009b). 20090930optimal saving in the presence of two risks. *Journal of Economics*, 96(3):277–288.
- Menezes, C., Geiss, C., and Tressler, J. (1980). Increasing downside risk. *The American Economic Review*, 70(5):921–932.
- Menezes, C. F. and Wang, X. H. (2005). Increasing outer risk. *Journal of Mathematical Economics*, 41(7):875–886.
- Mesnard, A. (2004). Temporary migration and capital market imperfections. *Oxford economic papers*, 56(2):242–262.
- Munshi, K. and Rosenzweig, M. (2016). Networks and misallocation: Insurance, migration, and the rural-urban wage gap. *American Economic Review*, 106(1):46–98.
- Myerson, R. (2017). Policy analysis with endogenous migration decisions: The case of left-behind children in China. Available at <https://ssrn.com/abstract=3058134>.
- Nguyen, C. V. (2016). Does parental migration really benefit left-behind children? comparative evidence from ethiopia, india, peru and vietnam. *Social Science & Medicine*, 153:230–239.

- Noussair, C. N., Trautmann, S. T., and Van de Kuilen, G. (2014). Higher order risk attitudes, demographics, and financial decisions. *Review of Economic Studies*, 81(1):325–355.
- Organization, W. H. (2018). *Air Pollution and Child Health: Prescribing Clean Air*. World Health Organization. <https://www.who.int/ceh/publications/air-pollution-child-health/en/>.
- Organization for Economic Cooperation and Development (OECD) (2008). *International Migration Outlook-SOPEMI 2008*. Available at <https://www.oecd.org/els/mig/internationalmigrationoutlook2008.htm>.
- Pinto-Jayawardena, K. et al. (2006). Left behind, left out: The impact on children and families of mothers migrating for work abroad: Summary report. Technical report, Save the Children in Sri Lanka, Colombo.
- Rosenzweig, M. R. and Stark, O. (1989). Consumption smoothing, migration, and marriage: Evidence from rural india. *Journal of political Economy*, 97(4):905–926.
- Rothschild, M. and Stiglitz, J. E. (1970). Increasing risk: I. a definition. *Journal of Economic theory*, 2(3):225–243.
- Rothschild, M. and Stiglitz, J. E. (1971). Increasing risk ii: Its economic consequences. *Journal of Economic theory*, 3(1):66–84.
- Sandmo, A. (1970). The effect of uncertainty on saving decisions. *The review of economic studies*, 37(3):353–360.
- Stark, O., Helmenstein, C., and Yegorov, Y. (1997). Migrants’ savings, purchasing power parity, and the optimal duration of migration. *International Tax and Public Finance*, 4(3):307–324.
- Stark, O. and Levhari, D. (1982). On migration and risk in ldc. *Economic development and cultural change*, 31(1):191–196.
- Tressler, J. and Menezes, C. F. (1980). Labor supply and wage rate uncertainty. *Journal of Economic Theory*, 23(3):425–436.
- Tuysuz, S. and Lubochinsky, C. (2019). The impact of macroeconomic news on us interest rates and stock indices conditional on their volatility. *European Journal of Business and Management Research*, 4(4).
- UNICEF (2018). *Country Office Annual Report 2018, China*. Available at https://www.unicef.org/about/annualreport/files/China_2018_COAR.pdf.
- Zhang, P. and Cain, K. W. (2017). Reassessing the link between risk aversion and entrepreneurial intention. *International Journal of Entrepreneurial Behavior & Research*.
- Zhou, M., Murphy, R., and Tao, R. (2014). Effects of parents’ migration on the education of children left behind in rural china. *Population and Development Review*, 40(2):273–292.

Appendix

1.A Proof proposition 1

The FOC is given by $F(y_1, y_2, Z_1, Z_2, m^*) = 0$, where m^* can be written as a function of y_1, y_2, Z_1 and Z_2 , $m^* = m(y_1, y_2, Z_1, Z_2)$.

The FOC becomes, then: $F(y_1, y_2, Z_1, Z_2, m(y_1, y_2, Z_1, Z_2)) = 0$.

It follows that $\forall k = y_1, y_2, Z_1, Z_2$, $\frac{\partial F}{\partial k} + \frac{\partial F}{\partial m} \frac{dm}{dk} = 0 \Leftrightarrow \frac{dm}{dk} = -\frac{\frac{\partial F}{\partial k}}{\frac{\partial F}{\partial m}}$.

Since the SOC is verified ($\frac{\partial F}{\partial m} < 0$), $Sign(\frac{dm}{dk}) = Sign(\frac{\partial F}{\partial k})$.

We obtain then the following:

$\frac{\partial F}{\partial y_1} = U^{(1,1)}(y_1, Z_1 m^*)$. If $U^{(1,1)} < 0$ then $\frac{\partial F}{\partial y_1} > 0$, if $U^{(1,1)} = 0$ then $\frac{\partial F}{\partial y_1} = 0$, if $U^{(1,1)} > 0$ then $\frac{\partial F}{\partial y_1} < 0$.

$\frac{\partial F}{\partial y_2} = \beta g'(m^*) V^{(2,0)}(y_2 + g(m^*), Z_2) < 0$.

$\frac{\partial F}{\partial Z_1} = U^{(0,2)}(y_1, Z_1 m^*) > 0$.

$\frac{\partial F}{\partial Z_2} = \beta g'(m^*) V^{(1,1)}(y_2 + g(m^*), Z_2)$. The sign of this expression depends on the sign of the second cross-derivative $V^{(1,1)}$ (since $g'(m^*) > 0$ by assumption). If $V^{(1,1)} < 0$ then $\frac{\partial F}{\partial Z_2} < 0$, if $V^{(1,1)} = 0$ then $\frac{\partial F}{\partial Z_2} = 0$, if $V^{(1,1)} > 0$ then $\frac{\partial F}{\partial Z_2} > 0$.

This ends the proof.

1.B Proof proposition 2

In order to compare $m_{\tilde{\epsilon}_{1w}}^*$ and m^* , we evaluate the first-order condition (1.4) (where $m_{\tilde{\epsilon}_{1w}}^*$ is determined) at m^* . We thus obtain

$$W'_{\tilde{\epsilon}_{1w}}(m^*) = -E[U^{(0,1)}(y_1 + \tilde{\epsilon}_{1w}, Z_1 - m^*)] + \beta g'(m^*) V^{(1,0)}(y_2 + g(m^*), Z_2), \quad (1.15)$$

that is equivalent to (using Eq. (1.2))

$$W'_{\tilde{\epsilon}_{1w}}(m^*) = -E[U^{(0,1)}(y_1 + \tilde{\epsilon}_{1w}, Z_1 - m^*)] + U^{(0,1)}(y_1, Z_1 - m^*) \quad (1.16)$$

In the case of the unemployment risk, $\tilde{\epsilon}_{1w} = [0, -k; 1-p, p]$, $E[U^{(0,1)}(y_1 + \tilde{\epsilon}_{1w}, Z_1 - m^*)]$ can be written as $(1-p)U^{(0,1)}(y_1, Z_1 - m^*) + pU^{(0,1)}(y_1 - k, Z_1 - m^*)$.

If $U^{(0,1)}$ is increasing (decreasing) in y_1 , i.e., $U^{(1,1)} \geq (\leq) 0$ then

$$\begin{aligned}
& U^{(0,1)}(y_1, Z_1 - m^*) \geq (\leq) U^{(0,1)}(y_1 - k, Z_1 - m^*) \\
& \Leftrightarrow pU^{(0,1)}(y_1, Z_1 - m^*) \geq (\leq) pU^{(0,1)}(y_1 - k, Z_1 - m^*) \\
& \Leftrightarrow (1-p)U^{(0,1)}(y_1, Z_1 - m^*) + pU^{(0,1)}(y_1, Z_1 - m^*) \geq (\leq) (1-p)U^{(0,1)}(y_1, Z_1 - m^*) + \\
& pU^{(0,1)}(y_1 - k, Z_1 - m^*) \\
& \Leftrightarrow U^{(0,1)}(y_1, Z_1 - m^*) \geq (\leq) E[U^{(0,1)}(y_1 + \tilde{\epsilon}_{1w}, Z_1 - m^*)] \\
& \Leftrightarrow W'_{\tilde{\epsilon}_{1w}}(m^*) \geq (\leq) 0 \text{ (Eq. (1.16) is positive (negative))} \\
& \Leftrightarrow W'_{\tilde{\epsilon}_{1w}}(m^*) \geq (\leq) W'_{\tilde{\epsilon}_{1w}}(m^*_{\tilde{\epsilon}_{1w}}) \\
& \Leftrightarrow m^*_{\tilde{\epsilon}_{1w}} \geq (\leq) m^* \text{ (by the second-order condition, } W'_{\tilde{\epsilon}_{1w}} \text{ is decreasing in } m\text{)}.
\end{aligned}$$

In the case of a zero-mean risk, by Jensen's inequality, $U^{(2,1)}(y, Z) \leq (\geq) 0$, $\forall (y, Z)$, implies that Eq. (1.16) is positive (negative), resulting in $m^*_{\tilde{\epsilon}_{1w}} \geq (\leq) m^*$.

This ends the proof.

1.C Proof proposition 5

In order to compare $m^*_{\tilde{\eta}}$ and m^* , we evaluate the first-order condition (1.8) at m^* . We obtain using Eq. (1.2)

$$W'_{\tilde{\eta}}(m^*) = \beta E[g'(m^*)\tilde{\eta}V^{(1,0)}(g(m^*)\tilde{\eta}, Z_2)] - \beta g'(m^*)V^{(1,0)}(g(m^*), Z_2) \quad (1.17)$$

The parent will stay longer (shorter) in destination D_2 than in D_1 ($m^*_{\tilde{\eta}} \geq (\leq) m^*$) if $E[\tilde{\eta}V^{(1,0)}(g(m^*)\tilde{\eta}, Z_2)] \geq (\leq) V^{(1,0)}(g(m^*), Z_2)$.

By Jensen's inequality, this occurs if the function $H(\eta) = \eta V^{(1,0)}(g(m)\eta, Z_2)$ is convex (concave) with respect to η , $\forall \eta$, and that is whenever $-g(m)\eta \frac{V^{(3,0)}(g(m)\eta, Z_2)}{V^{(2,0)}(g(m)\eta, Z_2)} \geq (\leq) 2$.

This ends the proof.

1.D Functional forms of parental utility functions

A number of theoretical papers in the migration literature assumed the additive separability for the parental utility function ($G(y, Z) = u_1(y) + u_2(Z)$, with $u'_1 > 0$, $u''_1 < 0$, $u'_2 > 0$ and $u''_2 < 0$) (Dustmann, 2003a; Myerson, 2017), suggesting that decision mak-

ers are correlation neutral.³⁴ Other possible functional forms include the non-separable form ($G(y, Z) = u(y + f(Z))$), with $u' > 0$, $u'' < 0$, $f' > 0$ and $f'' < 0$, where $f(Z)$ is the monetary equivalent of the child's human capital level Z), suggesting correlation aversion; and the multiplicative separability between the parent's earnings and the child's human capital ($G(y, Z) = u_1(y)u_2(Z)$, with $u_1' > 0$, $u_1'' < 0$, $u_2' > 0$ and $u_2'' < 0$), suggesting correlation loving.

1.E Increases in risk

We define the increases in risk, in this paper, via the concept of stochastic dominance. A stochastic change is the change from one probability distribution to another, and stochastic dominance allows to establish a partial ordering of these probability distributions. It allows, therefore, to compare distributions that have different moments of higher orders.

Consider two random variables $\tilde{\theta}_k$ and $\tilde{\epsilon}_k$ valued in some interval $[a, b]$ of the real line, with respective cumulative distribution functions F and G . Starting from $F_1 = F$ and $G_1 = G$, define iteratively for $z \in [a, b]$

$$F_{s+1}(z) = \int_a^z F_s(t)dt \text{ and } G_{s+1}(z) = \int_a^z G_s(t)dt, \text{ for } s \geq 1.$$

$\tilde{\theta}_k$ is said to be riskier than $\tilde{\epsilon}_k$ (or, $\tilde{\theta}_k$ is said to be dominated by $\tilde{\epsilon}_k$) via n th-order stochastic dominance ($\tilde{\theta}_k \preceq_{SD_n} \tilde{\epsilon}_k$) if $G_n(z) \leq F_n(z)$ for all z , and if $G_s(b) \leq F_s(b)$ for $s = 1, 2, \dots, n - 1$.

From Ingersoll (1987), we know that $\tilde{\theta}_k \preceq_{SD_n} \tilde{\epsilon}_k$ is equivalent to $E[f(\tilde{\theta}_k)] \leq E[f(\tilde{\epsilon}_k)]$ for all functions f with derivatives $f^{(1)}, f^{(2)}, \dots, f^{(n)}$ such that $(-1)^{s+1}f^{(s)} \geq 0$ for $s = 1, 2, \dots, n$. Hence, \preceq_{SD_n} represents the common preferences of all the decision makers whose preferences satisfy risk apportionment of degrees 1 to n , in the terminology of Eeckhoudt and Schlesinger (2006). These decision makers prefer to disaggregate risk across equiprobable states of nature.

When the first $n - 1$ moments of $\tilde{\theta}_k$ and $\tilde{\epsilon}_k$ are equal, n th-order stochastic dominance coincides with the Ekern (1980)'s concept of increase in n th-degree risk. In other words, the later implies that only the n th moment of the distribution will change. For example, adding a zero-mean noise term to the income distribution or equivalently constructing a mean-preserving spread of the income probability distribution that transfers weight from the center to the tails, while preserving the same mean, is a second-degree increase in the

³⁴ $u_2(Z)$ can be written as $\delta v(Z)$ where δ is a parameter that refers to the parent's degree of altruism toward the child.

income risk, as defined by Ekern (1980), or a “mean-preserving increase in risk” as defined by Rothschild and Stiglitz (1970).

A different type of changes in the income distribution is a mean-variance-preserving transformation. The later follows from pairing a mean-preserving spread and a mean-preserving contraction in a way that the effect of the spread occurs before the contraction. The net effect of such operation, when added to an income distribution, will transfer dispersion from the right to the left for each value of income without changing the mean and variance, resulting in a new distribution with more downside risk, as defined by Menezes et al. (1980), or equivalently a third-order increase in risk as defined by Ekern (1980). Equivalently, an increase in downside risk is characterized by a transfer of a zero-mean noise from higher wealth levels to equally likely lower ones, and the density function of income will be skewed to the left.³⁵

An increase in outer risk, which is equivalent to an increase in the fourth degree risk, is defined as a change in the distribution that relocates dispersion from the center to the tails, increasing the kurtosis, while keeping the three first moments of the distribution: the mean, the variance and the skewness unchanged (Menezes and Wang, 2005).

1.F Proof proposition 6

In order to compare the two optimal values, $m_{\tilde{\epsilon}_{1w}}^*$ and $m_{\tilde{\theta}_{1w}}^*$, we evaluate the first order condition (1.10) at $m_{\tilde{\epsilon}_{1w}}^*$, we have

$$W'_{\tilde{\theta}_{1w}}(m_{\tilde{\epsilon}_{1w}}^*) = -E[U^{(0,1)}(y_1 + \tilde{\theta}_{1w}, Z_1 - m_{\tilde{\epsilon}_{1w}}^*)] + \beta g'(m_{\tilde{\epsilon}_{1w}}^*) V^{(1,0)}(y_2 + g(m_{\tilde{\epsilon}_{1w}}^*), Z_2). \quad (1.18)$$

Using Eq. (1.4), this becomes

$$W'_{\tilde{\theta}_{1w}}(m_{\tilde{\epsilon}_{1w}}^*) = -E[U^{(0,1)}(y_1 + \tilde{\theta}_{1w}, Z_1 - m_{\tilde{\epsilon}_{1w}}^*)] + E[U^{(0,1)}(y_1 + \tilde{\epsilon}_{1w}, Z_1 - m_{\tilde{\epsilon}_{1w}}^*)]. \quad (1.19)$$

Following Ingersoll (1987) (see Appendix 1.E), we can easily prove that Eq. (1.19) is negative (positive), i.e., $m_{\tilde{\theta}_{1w}}^* \leq (\geq) m_{\tilde{\epsilon}_{1w}}^*$ (since $W'_{\tilde{\theta}_{1w}}$ is decreasing in m), if $(1)^{(1+s)}U^{(s,1)} \leq (\geq) 0, \forall s = 1, \dots, n$.

This ends the proof.

³⁵Skewness is a measure of the asymmetry of the probability distribution. Note that the increase in the downside risk implies (but is not implied by) a decrease in skewness, or equivalently, an increase in left skewness, as measured by the third central moment.

1.G Proof proposition 9

In order to compare $m_{\tilde{\zeta}}^*$ and $m_{\tilde{\eta}}^*$, we evaluate $W'_{\tilde{\zeta}}$ at $m_{\tilde{\eta}}^*$, we have (using (1.8))

$$W'_{\tilde{\zeta}}(m_{\tilde{\eta}}^*) = \beta E[g'(m_{\tilde{\eta}}^*)\tilde{\zeta}V^{(1,0)}(g(m_{\tilde{\eta}}^*)\tilde{\zeta}, Z_2)] - \beta E[g'(m_{\tilde{\eta}}^*)\tilde{\eta}V^{(1,0)}(g(m_{\tilde{\eta}}^*)\tilde{\eta}, Z_2)] \quad (1.20)$$

We introduce the following function G : $G(\eta) = \eta V^{(1,0)}(g(m_{\tilde{\eta}}^*)\eta, Z_2) \forall \eta$. Using this notation, the previous equation can equivalently be written as

$$W'_{\tilde{\zeta}}(m_{\tilde{\eta}}^*) = \beta g'(m_{\tilde{\eta}}^*) \left(E[G(\tilde{\zeta})] - E[G(\tilde{\eta})] \right) \quad (1.21)$$

Following Ingersoll (1987), we can prove that Eq. (1.21) is negative (positive), resulting in $m_{\tilde{\zeta}}^* \leq (\geq) m_{\tilde{\eta}}^*$, if $(1)^{(1+k)}G^{(k)} \geq (\leq) 0, \forall k = 1, \dots, n$. Moreover, calculations show that for $n = 1$, $G^{(1)}(\eta) \leq 0$ if and only if $-\eta g(m_{\tilde{\eta}}^*) \frac{V^{(2,0)}(g(m_{\tilde{\eta}}^*)\eta, Z_2)}{V^{(1,0)}(g(m_{\tilde{\eta}}^*)\eta, Z_2)} \geq 1$. And, it follows from standard induction arguments that, for any $k > 1$, $G^{(k)}(\eta) \leq (\geq) 0$ if and only if $-\eta g(m_{\tilde{\eta}}^*) \frac{V^{(k+1,0)}(g(m_{\tilde{\eta}}^*)\eta, Z_2)}{V^{(k,0)}(g(m_{\tilde{\eta}}^*)\eta, Z_2)} \geq (\leq) k$.

This ends the proof.

Chapter 2

Rural-urban migration as a risk coping strategy: The role of income differentials

2.1 Introduction

In developing countries where formal insurance and credit markets are imperfect, absent, or inaccessible, rural households faced with high variability of income must adopt various strategies to insure against income risks. Self-insurance mechanisms include, *inter alia*, informal risk-sharing arrangements among households of the same region and temporary migration to urban areas. Regarding the latter, the New Economics of Labor Migration (NELM) has hypothesized that migration can be used as a household strategy not only to maximize expected earnings, but also to reduce risks and overcome constraints associated with market failures, notably in credit and insurance (Stark and Levhari, 1982; Stark and Taylor, 1991). Yet, the empirical literature investigating the effects of income risk at the place of origin on the migration behavior reports mixed evidence. While Rosenzweig and Stark (1989) and Dillon et al. (2011) found evidence in support of the NELM in India and northern Nigeria, respectively, Jalan and Ravallion (2001) and Munshi and Rosenzweig (2016) showed that greater rural income risks inhibit migration to urban areas in China and India, respectively.¹

¹Measures of household income risk used in these studies include temperature-related variability interacted with household land holdings to form an idiosyncratic measure of agricultural income risk (Dillon et al., 2011), rainfall variance interacted with households' landholdings to predict each household's variance in profits (Rosenzweig and Stark, 1989), the variance of the estimated innovation errors from the household-specific income process (Jalan and Ravallion, 2001), and the coefficient of variation of the household income (Munshi and Rosenzweig, 2016).

Why would some rural households not rely on migration despite being faced with an income risk? In the case of mid-1980s China, Jalan and Ravallion (2001) explain their finding by the way rural land is managed. Chinese rural households are denied private ownership of agricultural land and are only granted land-use rights through contracts, according to criteria such as the household's labor force. Under these circumstances, the migration of some household members generates a risk of land expropriation. It is therefore possible that when agricultural household income is risky, the incentive to secure the allocated land increases, and hence decreases the probability to migrate. In a similar vein, Munshi and Rosenzweig (2016) suggest that what drives a low migration probability, even in the presence of income risk, is the fear of households that in the case of migration of one of their members, the loss in the informal network insurance exceeds the income gain.²

These studies are proposing that migration behavior under risk is mainly explained by one main opportunity cost, the loss of land or the loss of informal risk-sharing transfers, which may reduce income differentials, and therefore migration probabilities.³ Yet, this may not be the only explanation for the negative relationship between income risk and migration. Another explanation may lie in the households' preference for the certain resources they have in their place of origin against risky resources from migration, even with positive income differentials. Hence, in a risky context, whether income differentials affect migration decision or not becomes unclear.

To investigate this question, we build a theoretical model where rural farm households make migration decision under an aggregate income risk, hence when informal risk-sharing arrangements offer little to no protection.⁴ Moreover, we consider that the rural household's welfare depends not only on income but also on child human capital.⁵ Indeed, relying on the empirical evidence of the negative impacts of income risk on children's outcomes (Jensen, 2000; Maccini and Yang, 2009; Björkman-Nyqvist, 2013), we conjecture

²Morten (2019) shows that introducing risk sharing for households indeed reduces migration by 37 percentage points in rural India. The context that she considers is, however, different. Households respond ex-post to realized income shocks and not ex-ante to income risk. She suggests that this result can be explained by the fact that households, in the case of a realized income shock, would be net recipients of risk-sharing transfers, and therefore, they would consider post-transfer income differentials.

³Expected income differential, accounting for the probability of employment, has long been shown to be a prime determinant of rural-to-urban migration (Todaro, 1969), driving the rural labor force towards urban labor markets (e.g. Agesa, 2001; Zhu, 2002).

⁴Our focus on aggregate income risk stems from climate change that increases income risks for rural households, by increasing, for example, rainfall variance and temperature fluctuations (Pachauri and Reisinger, 2008).

⁵Including children's human capital or consumption in the parents' utility, in addition to the parental income, is not new in the theoretical literature of migration (Dustmann, 2003; Dustmann and Görlach, 2016; Myerson, 2017).

that migration is used not only to diversify income sources but also to protect, at least in part, against child human capital reductions. Given the definition we consider for the household’s utility function, our model allows also to test how the marginal utility of income changes when the level of child human capital increases, which contrasts with some theoretical papers in the migration literature that assume additive separability for the parental utility function, implying no interaction between the income and the children’s human capital levels in the parents’ utility function (Dustmann, 2003; Myerson, 2017). On the one hand, private tutoring, learning activities and better physical environment at home are important drivers of improvement for low school-performing children, which increases the marginal utility of income when having low school test scores. On the other hand, other activities that are complements for good educational performance, such as leisure activities, may be less enjoyable when having a low school performance, which therefore decreases the marginal utility of income. No study, to our knowledge, has ever empirically investigated this relationship.

The setting of our empirical testing is rural areas in China. Labor migration within this country has been increasing dramatically over time to reach a total of 291 million migrant workers in 2019 (National Bureau of Statistics, 2020). As the *hukou* system in China, which relates each citizen to her place of birth, entitles differential access to welfare benefits between local and non-local residents, as well as between urban and rural residents, migrants tend to leave their family behind in their place of origin, resulting in an estimated 69 million “left-behind” children in 2015 (UNICEF, 2018). We use a cross-sectional household survey for the year 2008 that we combine with county rainfall data used to construct the aggregate measure of the agricultural income risk. Furthermore, in order to account for the non-randomness and the selectivity of migration, we employ an empirical framework based on a switching regression model with endogenous switching that was first adopted by Nakosteen and Zimmer (1980) in the context of migration.

The contribution of this paper is twofold. First, it aims to contribute to the literature on the determinants of migration by exploring the effectiveness of migration as a risk coping strategy in the absence of informal risk-sharing arrangements. We particularly investigate the role of income differentials in determining the migration decision under risk.⁶ This exercise explicitly demonstrates that a negative expected urban-to-rural

⁶Using a macro-level framework, Marchiori et al. (2012) suggest that country-level rainfall deviations from the mean could affect international migration in sub-Saharan Africa through an economic geography channel. This channel consists of two main elements: urbanization and the ratio of GDP per capita between the immigration and the emigration countries. They test in a three-equation model the effect of rainfall deviations on the ratio of GDPs per capita, whose effect on the international migration rate is then given.

income difference, in the case of an aggregate income risk, decreases the probability of migration as a risk coping strategy, compared to a situation where the expected income differential is positive. We also show that this effect diminishes with higher levels of income differential. This result is policy-relevant. Households with a negative income differential may resort to other unwanted strategies to mitigate the risk. Particularly, it has been shown that, in the absence of migration opportunities, households may store unproductive forms of wealth as a precaution against risk. In the case of Chinese rural households, this precautionary wealth may go up to 15% of their savings (Giles and Yoo, 2007).⁷ This self-insurance mechanism may decrease the household welfare as it limits the available resources for consumption and investments in health, education or any other agricultural investments. Such strategy may even reinforce poverty traps for the poorer households. It can also lead to larger problems when precautionary wealth is kept away from formal financial institutions, such as negative effects for intermediation and macroeconomic growth (Giles and Yoo, 2007). It is therefore important to consider the role of income differentials in determining the ability of households to use migration to adapt to aggregate risks, and to design policies that can effectively reduce their vulnerability to these risks.

Second, this paper also fits into the theoretical body of literature on child human capital investment. In the context that we consider in this paper, we find statistically significant evidence that the marginal utility of the household income increases as the child human capital deteriorates. The best specification of the utility function to consider for these households is, therefore, the non-separability between the households' earnings and their children's human capital. More precisely, the household's preferences would be best captured when considering the monetary equivalent of the child's human capital status instead of its measured value. Moreover, this result suggests that, in the case of an agricultural income risk, each additional monetary unit is more desirable when children have lower school test scores. In the migration context, we can therefore expect that, if income differential is positive and the household is faced with an income risk, parents with children poorly performing at school may be more likely to migrate, compared to parents with better performing children.

The remainder of the paper proceeds as follows. In Section 2, we present the theoretical model underlying the analysis. Section 3 outlines the empirical model and our strategy for testing the different effects, and Section 4 describes our data. Section 5 provides the

⁷These households may also diversify their income into livestock and nonfarm activities. However, local labor opportunities may be limited, while livestock is costly in terms of capital inputs and entails other forms of risks.

main results of the empirical analysis with some robustness checks. Section 6 concludes.

2.2 Theoretical model

We build a simple theoretical framework where a rural household, with at least one child aged less than 16, has to make a decision about sending a parent for migration. Drawing on the NELM theory, we assume that the migration decision is made collectively by the household members. Under the assumption of absent, incomplete or inaccessible credit and insurance markets, migration can be used as a self-insurance mechanism, as it reduces the consequences of the occurrence of the income risk.⁸

We assume that the household's main activity is farming its own land and that the household cares about both its income and the child's human capital. Preferences are modeled by a bivariate utility function, $u(y, z)$, where y is the household's income from farm production and other off-farm activities, and z is the household's child human capital. We consider the following standard assumptions:

- u is twice differentiable;⁹
- The marginal utilities with respect to each argument are strictly positive ($u^{(1,0)} > 0$ and $u^{(0,1)} > 0$);
- The household is strictly risk averse, i.e. the utility function is strictly concave: $u^{(2,0)} < 0$, $u^{(0,2)} < 0$ and $u^{(2,0)}u^{(0,2)} - (u^{(1,1)})^2 > 0$.

We do not impose any restriction on the sign of the cross-second derivative of u , and we thus consider three possible cases: $u^{(1,1)} < 0$, $u^{(1,1)} = 0$ and $u^{(1,1)} > 0$. In the terminology of Epstein and Tanny (1980), the household is said to be correlation averse (neutral, loving) if $u^{(1,1)} < 0$ ($= 0$, > 0). For such a household, the marginal utility of income is lower (unchanged, higher) when the child has higher levels of human capital. Moreover, depending on whether preferences are correlation loving or averse, the child human capital can be a complement or a substitute for income.¹⁰

The household is exposed to an agricultural risk in the form of a crop failure with probability p ($0 < p < 1$). This risk induces two types of loss, a monetary one (D_y ,

⁸Ehrlich and Becker (1972) showed that market insurance and self-insurance are substitutes.

⁹The partial and the cross-derivatives $u^{(k_1, k_2)}$ of a utility function u with two arguments x_1 and x_2 are given by the following expression: $\frac{\partial^{k_1+k_2} u(x_1, x_2)}{\partial x_1^{k_1} \partial x_2^{k_2}}$, $\forall k_1 = 0, 1, 2, \forall k_2 = 0, 1, 2$.

¹⁰See Appendix 2.A.1 for details about the relationship between the correlation attitude of the household and the functional form of its utility function.

with $D_y > 0$) and a non-monetary one on the child's human capital (D_z , with $D_z > 0$). We assume that, facing an agricultural risk, the household would opt for farming and investment decisions that are the least sensitive to the risk, and therefore less profitable, making the household income lower (e.g., Rosenzweig and Binswanger, 1992).¹¹ Regarding the non-monetary loss, the negative effect on child human capital can be twofold. First, out of fear of having an even lower income if the risk is realized, households may reduce their expenditure on education or their consumption of nutritious food, health care and leisure. Second, financial difficulties may induce an economic pressure for parents causing a state of emotional distress and potential marital conflicts that would negatively affect the parent-child relationship, and therefore the children's human capital (Conger et al., 1999).

The household's utility is thus given by

$$U_0 = pu(y_0 - D_y, z_0 - D_z) + (1 - p)u(y_0, z_0). \quad (2.1)$$

If the household decides to send a parent for migration, two effects will be at play, for both the household income and the child human capital. First, the loss of the household's labor force to migration decreases their cropping income. We denote this decrease by δ_y (with $\delta_y > 0$). However, the money sent back by the migrant parent helps alleviating the previous negative effect, directly by increasing the per capita income and indirectly by stimulating crop production (Lucas, 1987; Rozelle et al., 1999). We denote this effect by Δ_y (with $\Delta_y > 0$).

Second, the inflow of remittances from the migrant parent may allow children left behind to have access to better nutritious food and better health care as well as to support their education. Remittances may also be used in a way that decreases the need for child engagement in household activities, initially induced by the absence of the migrating parent. These effects are aggregated into Δ_z (with $\Delta_z > 0$). However, the loss of parental time and family disruption may also mean less attention, supervision and care, and less study and leisure hours for the children left behind, inducing an adverse effect on the different child outcomes.¹² We denote this negative effect by δ_z (with $\delta_z > 0$).

¹¹In an economy where insurance and credit markets are imperfect, absent, or inaccessible, the household may rely on various informal coping strategies to alleviate the effects of financial uncertainty (Townsend, 1994; Udry, 1994). While these mechanisms may be effective against idiosyncratic shocks, they are unlikely to provide much insurance when faced with an aggregate income risk because of high spatial correlation (e.g., Fafchamps, 1992; Udry, 1994). Other geographical areas that are not affected by the risk may provide little or no help due to enforcement problems and information asymmetries (e.g., Morduch, 2005). Such strategies are, therefore, unable to prevent a decrease in the household income.

¹²See Antman (2013) and Askarov and Doucouliagos (2020) for a review.

Furthermore, we make the following assumptions:

- A1. The amount of remittances is “state-dependent”: $\Delta_y = \Delta_y^{1-p}$ in the good state of nature (no damage) and $\Delta_y = \Delta_y^p$ in the bad state of nature (damage state), with $\Delta_y^p > \Delta_y^{1-p}$.

This assumption, which is in accordance with the NELM theory, means that the amount of remittances is higher in the bad state of nature: under the altruistic motive for remittances, migrants send more money to their families with riskier incomes (Roberts and Morris, 2003).

- A2. The benefits to the child human capital from remittances are “state-dependent”: $\Delta_z = \Delta_z^{1-p}$ in the good state of nature and $\Delta_z = \Delta_z^p$ in the bad state of nature, with $\Delta_z^p > \Delta_z^{1-p}$.

As more remittances are sent in the bad state of nature, it is expected that they induce a higher beneficial effect on the child human capital. Evidence shows that increases in income in a single year have positive effects on children’s outcomes (Mayer, 2002).

- A3. In the good state of nature, the migrant parent’s absence is totally compensated with the remittances sent back home i.e. $\Delta_y^{1-p} = \delta_y$ and $\Delta_z^{1-p} = \delta_z$.

Empirical studies provided evidence for the positive net effect of migration and remittances on the household income (e.g. Taylor and Lopez-Feldman, 2010) and on the child human capital (e.g. Macours and Vakis, 2010; Azzarri and Zezza, 2011). However, for simplicity and as we are only interested in the case with agricultural income risk, we assume that, in case of no agricultural income risk, benefits directly and indirectly related to remittances are equal to the losses underwent by the child due to the absence of the migrant parent.

It follows that the household’s utility in case of migration is given by

$$U_1 = pu(y_0 - D_y + \hat{\Delta}_y, z_0 - D_z + \hat{\Delta}_z) + (1 - p)u(y_0, z_0) \quad (2.2)$$

where $\hat{\Delta}_y = \Delta_y^p - \delta_y$ (with $\hat{\Delta}_y > 0$ by assumptions A1 and A3) and $\hat{\Delta}_z = \Delta_z^p - \delta_z$ (with $\hat{\Delta}_z > 0$ by assumptions A2 and A3).

Migration occurs if and only if $U_1 - U_0 \geq \alpha$ where α is the psychological cost of migration¹³. In order to simplify notations, we pose $Y_0 = y_0 - D_y$ and $Z_0 = z_0 - D_z$. Therefore, migration will rationally occur whenever

$$\Delta U = u(Y_0 + \hat{\Delta}_y, Z_0 + \hat{\Delta}_z) - u(Y_0, Z_0) \geq \hat{\alpha} \quad (2.3)$$

where $\hat{\alpha} = \frac{\alpha}{p}$ is the adjusted cost of migration. Following Rey and Rochet (2004), we assume that $\hat{\alpha}$ can be decomposed as follows: $\hat{\alpha} = \alpha(X) + \epsilon$, where X is a vector of variables that affect the migration cost and ϵ is a random variable such that $\epsilon \sim N(0, 1)$ and of cumulative distribution function F . Using a Taylor expansion of order 2 to approximate the utility function around (Y_0, Z_0) , the probability of migration, $q (= p(\Delta U \geq \hat{\alpha}))$ can thus be approximated as:¹⁴

$$q \sim F[\beta_1 \hat{\Delta}_y + \beta_2 \hat{\Delta}_y^2 + \beta_3 \hat{\Delta}_z + \beta_4 \hat{\Delta}_z^2 + \beta_5 \hat{\Delta}_y \hat{\Delta}_z - \alpha(X)] \quad (2.4)$$

where $\beta_1 = u^{(1,0)}$, $\beta_2 = \frac{1}{2}u^{(2,0)}$, $\beta_3 = u^{(0,1)}$, $\beta_4 = \frac{1}{2}u^{(0,2)}$, $\beta_5 = u^{(1,1)}$, and $\alpha(X)$ is a function of variables related to the pecuniary and non-pecuniary costs of migration. $\hat{\Delta}_y$ and $\hat{\Delta}_z$ are respectively the income differential, defined as the difference in income between a situation where the household has a migrant in the urban labor market ($Y_0 + \hat{\Delta}_y$) and a situation where all household members stay in the rural labor market (Y_0), and the child human capital differential, defined as the difference in the child human capital from having a migrant parent ($Z_0 + \hat{\Delta}_z$) versus not having one (Z_0).

Eq. (2.4) shows that in the presence of agricultural income risk (p), both income differential $\hat{\Delta}_y$ and the child human capital differential $\hat{\Delta}_z$ affect the migration decision of the household. Given the assumption of non-satiation of the household, β_1 should be positive: in the case of an agricultural income risk, decreasing the income differential should decrease the probability of the parent's migration. Similarly, β_3 should be positive: in the case of an agricultural income risk, decreasing the child human capital differential should decrease the probability of the parent's migration. Moreover, given our assumption on households being strictly risk averse, β_2 should be negative: an inverse U-shaped relationship should exist between the household income differential and the probability to send a parent for migration, in the case of an agricultural income risk. Similarly, β_4 should be negative: an inverse U-shaped relationship should exist between the child human capital differential and the probability to send a parent for migration, in the case

¹³We call it a psychological cost because it is measured in expected utility terms.

¹⁴See details in Appendix 2.A.2

of an agricultural income risk. Finally, the sign of β_5 reflects how the marginal utility of the household's income changes with respect to the household's child human capital, in the case of an agricultural income risk. Due to the scarcity of theoretical and empirical works on this measure, the determination of its sign remains a pure empirical question.

2.3 Empirical model and econometric strategy

2.3.1 Empirical model

In order to investigate the decision to migrate, given by Eq. (2.4), we consider the continuous latent variable Mig_i^* , such that if $Mig_i^* > 0$, household i would send a parent for migration. We get the following empirical model:

$$\begin{aligned}
 Mig_i^* = & \beta_1(y_{1i} - y_{0i}) + \beta_2(y_{1i} - y_{0i})^2 + \beta_3(z_{1i} - z_{0i}) + \beta_4(z_{1i} - z_{0i})^2 \\
 & + \beta_5(y_{1i} - y_{0i})(z_{1i} - z_{0i}) + \beta_6 H_i + u_i
 \end{aligned} \tag{2.5}$$

We define Mig_i as a binary variable such that $Mig_i = 1$ if $Mig_i^* > 0$ and $Mig_i = 0$ otherwise. $(y_{1i} - y_{0i})$ and $(z_{1i} - z_{0i})$ are the differences in the household income and in the child human capital, from having a migrant parent *versus* not having one in the case of an income risk, for each household i , respectively. The migration costs are related to a set of observable household human capital and demographic characteristics, H_i , found to be important in the empirical literature and some other unobservable factors included in the equation's error term, u_i .

Our primary objective is to estimate the structural migration equation (3.3). However, we do not observe direct measures of the household income and of the child human capital for migrant households, had they not had a migrant parent, and for non-migrant households, had they had a migrant parent. To overcome this issue, we introduce into Eq. (3.3) fitted values of the household income and of the child human capital variables, resulting from an ordinary least squares (OLS) estimation of the household income and the child human capital equations. Accordingly, we define below the household income and the child human capital functions.

Suppose that y_{mivc} is the log of the total household income for household i living in village v in county c , with a non-migrant parent for $m = 0$ or a migrant parent for $m = 1$, such that:

$$y_{mivc} = \gamma_m J_{mi} + \theta_m \sigma_c + \phi_m S_v + \epsilon_{mivc} \tag{2.6}$$

where J_{mi} is a vector of household productive assets, including human capital and physical

capital characteristics and institutional benefits.¹⁵ σ_c is the aggregate county-level measure of income risk, for each household living in county c . Following previous literature on the determinants of income for rural Chinese households (e.g. Taylor et al. (2003); Du et al. (2005)), we further control for locational characteristics, S_v at the village level v , which allow to account for the differences in economic conditions across villages.

Similarly, suppose that z_{mivc} is the outcome of children from a household i living in village v in county c , with a non-migrant parent for $m = 0$ or a migrant parent for $m = 1$, such that:

$$z_{mivc} = \alpha_m K_{mi} + \tau_m \sigma_c + \psi_m S_v + \kappa_p + \eta_{mivc} \quad (2.7)$$

where K_{mi} is a vector, for each household i , of the household's children's individual characteristics, parents' educational attainment, and other household characteristics.¹⁶ σ_c is the aggregate measure of income risk, for each household living in county c . Following Meng and Yamauchi (2017), we also control for village-level characteristics (S_v) and province fixed effects (κ_p). The definition of all the variables used in the estimations is provided in Table 2.C.1, in Appendix.

2.3.2 Econometric strategy

Equations (3.3)-(2.7) constitute the basic structural form of our model. The problem with the above procedure is that estimating the household income and the child human capital equations using OLS yields biased results because households are not randomly assigned to migration status, and therefore, the income and the child human capital observed for each category of migrants are truncated non-random samples. To correct for truncation and selection bias, we adopt the Heckman and Lee two-steps procedure and produce the correct fitted values of the household income and of the child human capital variables.¹⁷ We can then estimate Eq. (3.3) by maximum likelihood probit techniques. This three-steps estimation procedure, including a switching regression model with endogenous switching and a structural decision equation, was first applied in the migration context by Nakosteen and Zimmer (1980).

¹⁵Variables of physical capital characteristics reflect the household's ability to generate income and to face monetary risk.

¹⁶We do not include the household per capita income or the remittance variables here. We cannot construct a counterfactual of remittances for stayers, had they migrated, and we worry that the household income and the children's human capital are jointly determined by some household characteristics that we do not observe. To overcome such problems and capture the income effect, we introduce the log of the household house value.

¹⁷Note that in what follows, we may refer to the income and child human capital equations as the outcome equations.

In the first step, a reduced form of the migration equation is obtained by substituting the household income and the child human capital equations into Eq. (3.3). The procedure suggests, in the second step, to correct the income and the child human capital equations by introducing the appropriate selectivity variables, $\hat{\lambda}_m$ (with $m = 0, 1$), and zero mean error terms, ζ_j (with $j = 1, 2, 3, 4$), as follows:

$$\begin{aligned}
y_{0i} &= \gamma_0 J_{0i} + \gamma'_0 \hat{\lambda}_{1i} + \theta_0 \sigma_c + \phi_0 S_v + \zeta_{1i}, \\
y_{1i} &= \gamma_1 J_{1i} + \gamma'_1 \hat{\lambda}_{0i} + \theta_1 \sigma_c + \phi_1 S_v + \zeta_{2i}, \\
z_{0i} &= \alpha_0 K_{0i} + \alpha'_0 \hat{\lambda}_{1i} + \tau_0 \sigma_c + \psi_0 S_v + \kappa_p + \zeta_{3i}, \\
z_{1i} &= \alpha_1 K_{1i} + \alpha'_1 \hat{\lambda}_{0i} + \tau_1 \sigma_c + \psi_1 S_v + \kappa_p + \zeta_{4i}.
\end{aligned} \tag{2.8}$$

Estimating these equations using OLS produces consistent results (Heckman, 1976). As error terms of households residing in the same county may be correlated, we cluster standard errors at the county level. We also compute them using a bootstrap procedure that accounts for the variation resulting from the estimated Inverse Mills Ratio (IMR). Finally, we can form consistent predictors for y_{0i} , y_{1i} , z_{0i} and z_{1i} and introduce them in the structural migration equation (Eq. (3.3)). The resulting estimates of the β 's should be consistent, while coefficient standard errors are bootstrapped to account for the use of the generated income and child human capital differentials.

2.3.3 Identification

The household income and the child human capital equations on the one hand, and the migration equation on the other hand, have a large set of variables in common. Even though we can assume that our model is technically identified through the non-linearity of the IMR, there is still a risk that the income and child human capital equations would yield fragile results if insufficient non-linearity occurs (Puhani, 2000). To avoid a collinearity problem in the second stage of the estimation, it is recommended to have at least one observed variable that affects why households may choose to participate in migration but does not have any influence on the outcome equations. Two instruments are used to satisfy this exclusion restriction. The first instrument, the past village-level migration network, consists of the ratio of migrant individuals in 2005 in the same village.¹⁸ Historical migration networks have been used by a number of papers, as an instrument for the migration variable, to investigate the effects of migration on the household income (e.g.

¹⁸Unfortunately, we do not have information about the village population in 2005, so we use that of 2007 to compute the ratio of migrant individuals in each village (assuming that the village population did not vary much in 2 years).

Taylor et al., 2003) as well as on the child outcomes (e.g. Meyerhoefer and Chen, 2011). These papers argue that previous migrants from the same village will form a network in the destination areas. The network access should help reducing the migration costs and risks, and provide more information, contacts and support for households back home in the subsequent years, and thus facilitating their migration without having any direct effects on the household’s income or on children’s outcomes. The second instrument, village labor-out, is a dummy variable that takes the value of 1 if the village collective organizes labor, finding jobs outside the village in 2008 and 0 otherwise. Its rationale is similar to having a historical network of migrants that facilitates migration and lowers its costs. Therefore, we expect that these two instruments will have a positive effect on the household decision to send a migrant in 2008 in the first step of the Heckman and Lee procedure, but will not be significantly correlated to the error terms of the outcome equations in the second step. Still, one may think that these two instruments may reflect unobserved factors of the local economy, and therefore, may be correlated with the current levels of the community development in each village. Thus, they could affect the current household income and children’s outcomes. We control for some public facilities at the village level that may indirectly be related to our outcome variables.

2.4 Data description

We use the 2009 Rural Household Survey (RHS) from the Rural Urban Migration in China (RUMiC) project (henceforth RUMiC-RHS), conducted between March and June of 2009 to collect information from 2008.¹⁹ The RUMiC-RHS inspected the situation of 8,000 rural households from 800 villages in 82 counties and nine provinces: Hebei, Jiangsu, Zhejiang, and Guangdong from eastern China; Anhui, Henan, and Hubei from central China; Chongqing and Sichuan from western China. A wide range of individual and household level variables are covered by this survey including not only the demographic, social and economic information, but also records of the migration history, household income and child human capital variables, particularly important for our empirical testing. A detailed village survey is also carried out along the household survey.

Following the National Bureau of Statistics’ definition, we consider as a migrant

¹⁹The RUMiC project, which started in 2008, includes yearly surveys on rural, urban, and migrant households. We use the second wave of the RUMiC-RHS since some variables that are important for our analysis were only collected from this wave. These variables include the children’s school test scores and land size. Furthermore, in order to avoid a simultaneity bias and to account for the fact that the migration decision was made in the preceding year, we include the lags of most of our variables from the previous year’s survey.

worker, any person who lived at least six months outside the local countryside in 2008, for work or business purposes.²⁰ Both within and outside the county of origin movements are considered. Regarding household incomes, the total net income includes wages (wages from local off-farm activities and remittances), net incomes from family agricultural and non-agricultural activities, net property incomes and net transfer incomes. Parents or guardians were also asked to report their children’s Chinese and mathematics scores from the final exams of the last school term.²¹ We use these scores as measures of the child human capital.²² Following Meng and Yamauchi (2017), who exploited the RUMiC-RHS data to investigate the effect of cumulative parental migration on child education, we use normalized test scores, defined as the actual test score divided by the full score applied in the child’s school and multiplied by 100. According to Meng and Yamauchi (2017), there are no differences in the textbooks used in schools of the same province or prefecture. Therefore, we follow them and introduce province fixed effects when studying the determinants of children’s test scores in order to account for possible inconsistencies across schools from different provinces.²³

We measure agricultural income risk through county-level rainfall variation and use the ratio of the standard deviation and the mean of rainfall during the months of March to October, computed over 52 years of monthly rainfall data (January 1960 - December 2012) for different weather stations across China.²⁴ We collected the data from the

²⁰As the Chinese urban labor market was affected by the financial crisis at the end of 2008, the migration decision and the return rate of migrants might have also been affected. Kong et al. (2010) investigated this issue and concluded that there was a decrease in the migration rate following the economic downturn of the 2008 crisis. However, Dutronc-Postel (2019) argued that their findings could be due to the fact that their survey data includes very short distance migrations. Moreover, the actual onset of the negative consequences of this crisis started at the end of 2008. Therefore, any negative effect should be on those who decided to migrate at the end of 2008 or on the migration duration of those who migrated before the crisis hits the Chinese labor markets, resulting in them to be counted as non-migrant in our framework. On the one hand, we are not interested in the potential migrants deciding their migration by the end of 2008 since we define as migrant any person with a migration duration of at least 6 months in that year. On the other hand, Dutronc-Postel (2019) provided evidence that the economic slowdown did not have a substantial nor a significant effect on the duration of migration in 2008. Therefore, we do not expect the economic crisis to have strong effects on the migration decisions in our survey.

²¹In China, schools usually send report cards to parents and require that they are returned with the parents’ signatures (Zhao, 2015; Meng and Yamauchi, 2017). This suggests that parents or guardians who report this information are very likely to be aware of the children’s school results.

²²Three different specifications are used for the child human capital variables: we compute, for each household, either the mean of all children’s test scores, or, in two alternative specifications, the test score of the oldest or the youngest child, in each household.

²³Exams from schools of different counties within a province may still present some differences, which cannot be controlled for.

²⁴Variability of rainfall distribution has been captured by either the variance (Giles and Yoo, 2007), the standard deviation (Paxson, 1992) or the rainfall coefficient of variation (Rose, 2001). It is better to rely on the coefficient of variation as a measure of the riskiness of the environment since, unlike the variance and the standard deviation, this measure is not sensitive to scaling (Rose, 2001). See Appendix

National Oceanic and Atmospheric Administration’s (NOAA) Global Summary Of the Month (GSOM) precipitation data, which contains monthly summaries computed from stations in the Global Historical Climatology Network (GHCN)-Daily dataset.²⁵ About 94% of the data is originally collected at China’s National Meteorological Information Center and has received thorough quality checks. In addition to monthly precipitation records, the latitude and longitude of each station’s location is included in the data. We rely on this location information to match each county represented in the RUMiC-RHS survey to the nearest weather station.²⁶ The rainfall data we use exhibit variability across counties as well as within counties over the years.

We make a number of restrictions on the initial sample in order to conduct our empirical analysis, with a focus on agricultural households with children. First, we restrict the sample to rural households with a farming activity and we drop households with no agricultural land and/or no member working in agriculture in 2008. We also exclude households that do not have any member in the labor force²⁷ and those that do not have at least a child aged between 6 and 15 or a child aged between 16 and 22 and at school. We further drop households with intra-county migrants that worked in the agricultural industry, resulting in a sample of 3,711 households. Dropping households with missing values for their total net income and those whose migrants do not send remittances leads to a sample of 3,464 households. In addition, we exclude households whose children have missing information about their test scores and whose children dropped out of school in 2008, which reduces the sample to 2,884 households. Regarding the number of migrants within the household, keeping households where one or both parents migrate further restricts the sample to 2,507 households, while keeping households where only one parent migrates reduces the final sample to 2,268 households.

Table 2.C.2 in Appendix checks whether this final sample of 2,268 households, where only one parent can be a migrant, is random. To do so, we focus on the 3,711 households that can be potentially covered in our analysis and compare those who are included with those who are excluded from our final sample. Results of estimating a dummy variable indicating whether the household is covered in our preferred sample on a vector of household-level variables, controlling for provincial fixed effects, suggest few significant

2.B for details about the choice of the period of March to October.

²⁵This dataset is more complete and up-to-date than the GHCN-Monthly version 2 precipitation dataset. The data are available at <https://gis.ncdc.noaa.gov/maps/ncei/cdo/monthly>.

²⁶The number of weather stations changed over time, so in some cases, we linked more than one station to the same county.

²⁷We define members in the labor force as individuals aged between 16 and 65 (not retired) or more than 65 but still working, who do not have any physical disability that affects their work capabilities, and are not currently at school.

differences. First, as expected, the number of migrants is lower in the sample we are using, since we focus on households with only one migrating parent. We also find that the household income and the number of children aged between 6 and 15 are positively associated with the inclusion in the final sample, while the household size and the labor ratio are negatively correlated with inclusion in the final sample. Included households have, therefore, fewer members, less members in the labor force, but higher incomes and more children aged between 6 and 15. Note that we control for any differences that might arise from these differences in all estimations.

Tables 2.C.3 to 2.C.5 display various summary statistics, both for the overall sample and by migration status. Table 2.C.3 highlights a number of significant differences between households with a migrant parent and those without a migrant parent in terms of household composition, education and wealth. Table 2.C.4 also suggests that households with a migrant parent have significantly lower net total incomes, while Table 2.C.5 documents child characteristics and indicate that children with both parents at home score higher, on average, in both Chinese and math tests than their counterparts with one migrating parent.

2.5 Empirical results

2.5.1 Structural equation of migration

Our baseline estimates of the structural form of the household decision to send a parent for migration, as presented by Eq. (3.3), are shown in Table 2.5.1. The table provides estimated coefficients and bootstrapped standard errors, using different specifications. In our benchmark specification, presented in columns (1) and (2), the mean of the predicted school test scores for all children for each household is used to build the child human capital differential variable. In columns (3) to (6), we use two alternative ways to deal with the child human capital variable, by considering the human capital of either the eldest (columns (3) and (4)) or the youngest (columns (5) and (6)) child among the household's children, for each household.²⁸ We also use two separate measures of the child human

²⁸In our preferred sample where only one parent may be a migrant, around 70% of households have only one child aged between 6 and 22 (at school), 25% have two children and almost 5% have three or four children. For simplicity, in the different specifications where we use the mean of test scores of all children in the same household or the test score of the oldest or the youngest child in the household, we estimate equations (2.7) using all children in each household. We then compute the predicted values of test scores and the mean of each household's children's test scores, or we keep the test score of the oldest or the youngest child in each household, depending on the specification we are interested in.

capital variable. The first relies on math scores (columns (1), (3) and (5)) and the second on Chinese scores (columns (2), (4) and (6)).²⁹

Results in Panel A, where only one parent is a migrant, confirm the predictions of the theoretical model. Of particular interest is the estimated coefficient on the expected income differential, which is positive and significant. This result confirms our assumption about the risk aversion of the households. It also shows that when households face an agricultural income risk and use migration as a coping strategy, the income differential remains a significant determinant of the migration decision. A positive expected income differential increases the probability to migrate for households that face an income risk. However, the effect significantly decreases with higher levels of income differential. This result suggests that households make their migration decision depending on the level of the income differential they are expecting. Focusing on the sample where only one parent is a migrant, we find that the effect of income differentials starts decreasing when the expected income of the household with a migrant parent is around 1.32 to 1.38 their expected income when they do not have a migrant parent.³⁰ This result can be explained in two ways. First, a higher expected income differential may be due to higher remittances, hence to higher income for the parent in the destination area. If the latter is related to expected higher risks, the income risk in the destination area would increase compared to that in the place of origin. Hence, given the risk aversion of the household, the probability of migration would decrease. Second, a higher expected income differential may also be due to a lower expected reduction in the household income due to the absence of the parent. If the latter is related to a lower income risk, the income risk in the area of origin would decrease compared to that at the destination area. Hence, given the risk aversion of the household, migration probability would decrease.³¹ Similarly, coefficients on the child human capital differential and its square are statistically significant at 1% level and of expected signs. This result suggests that households also care about the human capital of their children, implying that economic incentives are not the only determinants of migration in China when households face an income risk.

Another key coefficient is the one on the interaction between the expected income differential and the expected child human capital differential. Table 2.5.1 shows a negative

²⁹Note that the variable of math scores is our preferred measure of child human capital, as they are generally considered more informative of learning and are more frequently used in the education literature.

³⁰Given our definition of the income differential variable, we apply the exponential function to identify the location of the turning point in the curve of the income differential variable. The reported turning points are computed using math test scores as a measure of the child human capital levels.

³¹Dustmann et al. (2020), using the 2009 RUMiC-RHS, found evidence that the average risk aversion level of households is negatively associated with the migration probability.

Table 2.5.1: Estimates of the structural model of migration

	(1)	(2)	(3)	(4)	(5)	(6)
A. Only one parent is a migrant						
<i>Expected changes</i>						
Income differential	1.878*** (0.574)	1.442** (0.638)	1.767*** (0.576)	1.318** (0.648)	1.998*** (0.562)	1.553** (0.608)
Income differential ²	-3.158*** (1.204)	-3.479** (1.687)	-3.215*** (1.204)	-3.573** (1.693)	-3.071** (1.200)	-3.315** (1.652)
Child human capital differential	0.122*** (0.033)	0.345*** (0.036)	0.121*** (0.032)	0.338*** (0.037)	0.123*** (0.033)	0.348*** (0.034)
Child human capital differential ²	-0.008*** (0.002)	-0.014*** (0.004)	-0.007*** (0.002)	-0.013*** (0.004)	-0.008*** (0.003)	-0.014*** (0.004)
Interaction	-0.090 (0.071)	-0.194* (0.109)	-0.103 (0.070)	-0.220** (0.107)	-0.074 (0.071)	-0.171 (0.109)
Observations	1767	1767	1767	1767	1767	1767
B. At least one parent is a migrant						
<i>Expected changes</i>						
Income differential	2.257*** (0.518)	1.515*** (0.447)	2.208*** (0.519)	1.415*** (0.452)	2.368*** (0.502)	1.662*** (0.432)
Income differential ²	-2.729*** (0.936)	-3.294*** (0.930)	-2.695*** (0.928)	-3.345*** (0.918)	-2.830*** (0.941)	-3.200*** (0.940)
Child human capital differential	-0.325*** (0.048)	0.067* (0.035)	-0.290*** (0.046)	0.072** (0.035)	-0.348*** (0.047)	0.062* (0.034)
Child human capital differential ²	-0.011*** (0.003)	-0.021*** (0.004)	-0.009*** (0.003)	-0.019*** (0.004)	-0.013*** (0.003)	-0.021*** (0.004)
Interaction	-0.060 (0.076)	-0.144* (0.081)	-0.062 (0.073)	-0.152* (0.079)	-0.044 (0.076)	-0.124 (0.080)
Observations	1951	1951	1951	1951	1951	1951
C. At least one household member is a migrant						
<i>Expected changes</i>						
Income differential	-0.123 (0.805)	0.377 (0.705)	0.105 (0.760)	0.245 (0.698)	-0.072 (0.805)	0.510 (0.702)
Income differential ²	-2.183*** (0.823)	-1.897*** (0.625)	-1.922** (0.777)	-1.904*** (0.626)	-2.603*** (0.850)	-1.908*** (0.626)
Child human capital differential	-0.503*** (0.068)	-0.156** (0.066)	-0.429*** (0.061)	-0.130** (0.065)	-0.558*** (0.066)	-0.180*** (0.064)
Child human capital differential ²	-0.001 (0.004)	-0.009** (0.004)	0.001 (0.004)	-0.008** (0.004)	-0.005 (0.004)	-0.011*** (0.004)
Interaction	-0.145 (0.098)	-0.006 (0.084)	-0.111 (0.088)	-0.022 (0.081)	-0.132 (0.101)	0.010 (0.085)
Observations	2226	2226	2226	2226	2226	2226
Household Characteristics	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The dependent variable is, in panel A, a dummy variable that equals 1 if only one parent is a migrant and 0 otherwise, in panel B, a dummy variable that equals 1 if one or the two parents are migrants, and in panel C, a dummy variable that equals 1 if any household member is a migrant. Columns (1), (3) and (5) use math test scores as the measure of child human capital, while Columns (2), (4) and (6) use Chinese test scores. In Columns (1) and (2), we use the average of test scores of children in the same household, while we use in Columns (3) and (4), the test score of the oldest child in the household, and in Columns (5) and (6), the test score of the youngest child in the household. The interaction variable refers to the interaction term between the income differential and the child human capital differential. All regressions control for household characteristics (land size, mean household age, mean age squared, mean schooling, gender ratio, labor ratio, household size, the number of preschool children, school children (age<16), school children (age≥16), elderly (>60) and disabled members). Bootstrapped standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

sign of this coefficient, although the effect is significant at the 1% level only with Chinese score as the measure of the child human capital. In the context that we consider in this paper, the negative sign provides evidence for a decrease in the marginal utility of income following an increase in the child human capital level, i.e., households are correlation averse ($u^{(1,1)} < 0$). In other words, when faced with an income risk and when migration is used as a coping strategy, the household generates a higher satisfaction from each additional monetary unit they earn if the human capital of children is lower. Furthermore, as explained in Appendix 2.A.1, this result also allows to draw conclusions about which functional form of the household utility best describes the households' income-child human capital trade-off choices. In this context, our negative estimate of $u^{(1,1)}$ implies that the non-separability between the household's earnings and the child's human capital is to be considered. More precisely, the household's preferences would be best captured when considering the monetary equivalent of the child's human capital status instead of its measured value.³²

Results in Panels B and C, where one or two parents may be migrants and where any household member may be a migrant, respectively, confirm our findings on the effect of income differential and the interaction term of income differential and child human capital differential. Moreover, as the effects are likely to vary with the duration of parental absence, we replicate our estimations considering as migrants parents who were away from home for at least 3 months or for at least 9 months. We report the structural estimation of the migration equation in Appendix Table 2.C.6. Overall, the results remain the same, except for the coefficients on the income differential and the interaction term, which become less precisely estimated in the case of 9-month migration.

Appendix Table 2.C.7 shows the details of the structural migration estimation, using the sample where only one parent may be a migrant.³³³⁴ We find that more years of

³² $u(y, z) = \mu(y + f(z))$ with $\mu' > 0$, $\mu'' < 0$, $f' > 0$ and $f'' < 0$, where $f(z)$ is the monetary equivalent of the child's human capital level z .

³³All household characteristics are that of 2007, the year preceding the migration year, except for the land size variable. Land size information were not reported in 2007, hence the use of the 2008 data for this variable. Considering the sample used in Table 2.C.7, only 9% of the households reported that their land has been adjusted in the last 5 years. Unfortunately, we cannot have more precise information about whether the changes happened between 2007 and 2008 or before 2007. This is important as the household land may decrease following the migration of one of its members. As a robustness check, we re-estimate our models while dropping households that had their land adjusted in the last 5 years, results remain the same (estimations are not reported for simplicity).

³⁴The specification of the structural migration equation provides some important identifying restrictions, in that the migration cost is assumed independent of variables including the coefficient of variation of rainfall, the irrigated land, access to credit and some child individual characteristics. These variables are assumed to affect the household decision to send a parent for migration only through their effect on the expected household income and/or the expected child human capital, hence their exclusion from the structural probit equation.

schooling of the household's labor force members decrease the probability to send a parent for migration. This result shows that better educated households may rely on strategies other than the short-term migration to diversify income. This is not surprising as the majority of short-term rural migrants in China occupy manual jobs that local residents are unwilling to take, in the destination areas (Meng, 2012).³⁵ Around 42% of migrants, surveyed in the 2009 RUMiC-RHS, worked in the manufacturing industry while around 19% of them in the construction industry and around 11% in the services industry. In accordance with prior research (e.g. Zhu, 2002; Mullan et al., 2011), we find a significantly negative effect of the household land size on the probability to send a parent for migration, in the specification using math score as the measure of child human capital. This finding confirms that the tenure of land provides a key source of employment and livelihood for rural households and, therefore, reduces the probability to migrate.³⁶ We also find that the higher the mean age of the household, the more likely it is to send a parent for migration.³⁷ Indeed, age reflects personnel connections and the accumulation of knowledge and experience for the household, hence motivating migration. However, this effect decreases over time. This may also be explained by the type of jobs short-term migration offer. The ability to land these jobs decreases for older workers. This quadratic relationship between migration probability and age has been confirmed by various studies in the case of individual migration decision in China (e.g. Giles and Mu, 2007; Dustmann et al., 2020). Another interesting finding is the significant and positive coefficient on the gender ratio. It shows that the higher the number of males among the household members is, the higher is the likelihood of the household to send a parent for migration. This result is consistent with the literature showing that migration from rural areas is dominated by males. Even though this trend is decreasing in recent years, it is still important among new generation migrants (those born after 1980) in China (Zhao et al., 2018). When migration is considered as a household decision, a larger household size may encourage migration by providing a device for risk diversification, in the absence of credit and insurance markets (Stark and Taylor, 1991). Some previous studies have confirmed this positive relationship in China (Zhu, 2002; Taylor et al., 2003), while others showed that the number of siblings, the number of working-age men and women in the household

³⁵Li and Zahniser (2002), using data from 1995, suggested that the education effect on the individuals' decision to migrate in China is quadratic, where the migration probability increases over the first seven years of schooling, then declines thereafter. Giles and Mu (2007), on the other hand, showed that the average number of years of education of household residents decreases the migration probability.

³⁶Other studies also found a significant positive relationship between land and migration in China (see e.g. Rozelle et al., 1999; Taylor et al., 2003.)

³⁷Tsegai (2007) reported a positive but insignificant effect of the mean age of the household's adult members on the migration decision of Ghanaian households.

decrease the probability to migrate (e.g., Giles and Mu, 2007). In our analysis, we show that, overall, a larger household size hinders migration of parents. Going into the details, we find that the labor ratio is positive but only significant at the 10% conventional level when using the Chinese test score of the youngest child in each household as a measure of the child human capital level. This means that households with a higher proportion of dependents compared to the proportion of workers are less likely to send a parent for migration. Considering the dependent members in the household, we find, contrary to previous research (e.g., Giles and Mu, 2007; Mullan et al., 2011), that the presence of children increases the probability of migration. This may be explained by the additional economic responsibilities related to more children in the household. Moreover, children, particularly older ones, may be a source of labor both for domestic and farming activities, replacing, in part, the absence of the migrating parent (Chang et al., 2011), hence explaining the estimated positive coefficient. The effect of pre-school children on the migration of the parent may also be explained by the fact that this effect is migrant-gender-related. The majority (62%) of married migrants in the 2009 RUMiC-RHS dataset are males, while studies suggest that Chinese fathers are less involved with the care activities of these children (de Bruin and Liu, 2020). Indeed, Li and Zahniser (2002) found that more pre-school children in the household significantly decrease the migration of mothers but not that of fathers. However, we find that the migration probability is insensitive to the presence of dependent members that are aged more than 60 or are disabled. Finally, in line with other studies (e.g., Rozelle et al., 1999; Taylor et al., 2003; McKenzie and Rapoport, 2007), we find that network variables, in terms of the share of migrants from the same village and the assistance of the village in finding work outside of the village, are positively associated with the migration probability.

2.5.2 The income and child human capital equations

Although the income and child human capital equations are incidental in getting consistent estimates of the structural migration equation, they deserve to be presented. Table 2.5.2 and Table 2.5.3 show the estimates for these equations corrected for sample selection bias. Overall, the coefficients exhibit the expected signs.³⁸ Higher years of education, the household size and the household's labor force significantly increase a household's income. Richer households are also able to assure higher incomes. Access to formal credit through banks or credit unions significantly increases the household's income only for non-migrant households. Some services provided at the village level

³⁸All explanatory variables are that of 2008.

also significantly allow to achieve higher incomes, particularly when the village provides a unified drainage and irrigation system or a united production material purchasing service. The significant and positive coefficients on the regional dummies suggest that households living in eastern and center regions earn substantially higher incomes compared to those living in western regions. More importantly, we find that the rainfall coefficient of variation has a negative effect on the household total net income. This effect is significant, at the conventional 5% level, in the case where the household has no migrants, and at the 10% level if the household has a migrating parent. This means that facing riskier distributions of rainfall increases the likelihood to get lower incomes. In particular, the income risk reduces the household income by around 8.6% if the household has no migrants in 2008 and by only 5.8% if the household has one migrating parent. In fact, the riskiness of the environment is expected to induce a decrease in the agricultural income and an increase in the amount of remittances; however, the amount of remittances is unlikely to cover all the loss generated by the increase in the risk levels.

Similarly, we find that a higher degree of uncertainty in the distribution of rainfall induces a decrease in the children's school math test scores, even though the estimates are not statistically significant because of the high levels of standard errors. The effect of risk can be twofold. A negative effect is expected through the decrease in the agricultural income and the change of the parental behavior (quantity and/or quality of time), while a positive effect is expected through the increase in remittances and the change in the time use for children.³⁹ Moreover, males with no migrant parents, older children and wealthier children whose parents are migrants get lower scores. However, children with no siblings, compared to those with two siblings, those with more educated parents and those with a migrant parent but with more female adults in the household have higher scores. Finally, given the high standard errors of the selection variables in the different estimations, we cannot reject the hypothesis that the error terms of the migration and the outcome equations are uncorrelated. Income and child human capital regressions do not seem to suffer from the problem of selection on unobservable characteristics. Similar result has been found in related studies. Zhu (2002), for example, found non-significant coefficients on the selection variables in the case of Chinese male and female migrants' samples and in the female non-migrants' sample.

³⁹Using the samples where one or the two parents are migrants and where any household member is a migrant, we find similar results for the risk variable.

Table 2.5.2: Estimates of the household income corrected for sample selection bias

	Household income	
	(1)	(2)
<i>Household characteristics</i>		
Mean schooling	0.057*** (0.010)	0.037** (0.015)
Male headed	0.134 (0.101)	-0.157 (0.101)
Household size	0.071*** (0.016)	0.105*** (0.025)
Labor ratio	0.005*** (0.002)	0.004* (0.002)
<i>Physical capital</i>		
Land size	0.006 (0.008)	-0.008 (0.009)
Irrigated land	0.000 (0.010)	0.019 (0.013)
House value	0.091*** (0.019)	0.049** (0.025)
<i>Institutional assets</i>		
Access to formal credit	0.137*** (0.046)	-0.093 (0.067)
Access to informal credit	0.086 (0.060)	0.049 (0.121)
<i>Risk variables</i>		
Rainfall Coefficient of Variation (Mar-Oct)	-0.086** (0.035)	-0.058* (0.033)
<i>Selectivity variables</i>		
Inverse Mills ratio	-0.032 (0.181)	0.027 (0.165)
<i>Village characteristics</i>		
Unified irrigation system	0.130** (0.064)	0.041 (0.091)
Furrow machine	0.160 (0.105)	0.001 (0.169)
Plant disease prevention and treatment	-0.005 (0.087)	-0.052 (0.134)
United purchasing service	-0.037 (0.120)	0.333** (0.162)
<i>Regional characteristics</i>		
East	0.363*** (0.091)	0.280** (0.134)
Center	0.212** (0.091)	0.168 (0.148)
Observations	1979	402

Notes: The sample where only one parent can be a migrant is used here. The dependent variable is the logarithm of the household total net income, for the sub-sample of households without a migrant parent in Column (1) and for the sub-sample of households with a migrant parent in Column (2). Bootstrapped standard errors, in parentheses, are clustered at the county level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 2.5.3: Estimates of the child human capital corrected for sample selection bias

	Math score		Chinese score	
	(1)	(2)	(3)	(4)
<i>Child characteristics</i>				
Age	-0.691*** (0.074)	-0.825*** (0.230)	-0.632*** (0.093)	-0.786*** (0.223)
Male	-0.728 (0.475)	0.112 (1.522)	-1.831*** (0.444)	-1.233 (1.169)
Eldest Child	0.483 (0.635)	-0.554 (1.612)	0.127 (0.600)	-1.188 (1.516)
One sibling	1.641 (1.772)	3.287 (2.639)	1.548 (1.418)	2.500 (1.944)
No sibling	1.600 (1.891)	6.175** (2.657)	1.054 (1.496)	3.355 (2.132)
<i>Parents characteristics</i>				
Parents' years of schooling	0.751*** (0.201)	1.573*** (0.419)	1.091*** (0.211)	1.876*** (0.533)
<i>Household characteristics</i>				
Number of female adults (>15)	0.766 (0.631)	2.019 (1.881)	-0.387 (0.845)	2.681** (1.310)
Number of male adults (>15)	0.488 (0.466)	-2.134 (1.874)	-0.183 (0.458)	-2.213 (1.547)
Eldery (>60)	-0.155 (0.720)	0.755 (1.546)	0.844 (0.700)	1.231 (1.279)
Land size	-0.112 (0.086)	0.313 (0.282)	-0.112 (0.106)	-0.236 (0.256)
House value	0.362 (0.342)	-0.750 (0.541)	0.163 (0.304)	-1.074** (0.525)
<i>Risk variables</i>				
Rainfall Coefficient of Variation (Mar-Oct)	-0.559 (0.723)	-0.271 (1.237)	-0.559 (0.698)	-0.026 (1.116)
<i>Selectivity variables</i>				
Inverse Mills ratio	1.454 (3.373)	3.859 (4.177)	-0.333 (3.295)	3.965 (4.117)
<i>Village characteristics</i>				
Primary school in the village	0.123 (0.923)	-0.265 (2.340)	-0.530 (0.780)	-0.853 (2.177)
Province fixed effects	Yes	Yes	Yes	Yes
Observations	1972	400	1969	401

Notes: The sample where only one parent can be a migrant is used here. The dependent variable is the math score, for the sub-sample of households without a migrant parent in Column (1) and for the sub-sample of households with a migrant parent in Column (2), and the Chinese score, for the sub-sample of households without a migrant parent in Column (3) and for the sub-sample of households with a migrant parent in Column (4). Bootstrapped standard errors, in parentheses, are clustered at the county level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

2.6 Conclusion

In this paper, we investigate the ability of rural households to adapt to aggregate risk using migration. We particularly explore how income differentials interact with the risk coping motive to shape the final migration decision. Understanding such effects are relevant for policy making in light of the recent increasing problems of climate change. To do so, we have established a model of migration behavior under agricultural income risk, where the rural household's utility depends on their income and their children's human capital. We show, theoretically, that when migration is used as a coping strategy, the household's likelihood to migrate still depends on the household income differential, however, differently from their traditional definition, expected income differentials are now additionally determined by the agricultural income risk the household is facing. We estimated this model using data from China, and we employed a switching regression model with endogenous switching in order to account for the possibility that the rural-to-urban migration may be a self-selection mechanism. We show that the incidence of migration as a risk coping strategy is relatively higher for households with a positive expected income differential, compared to those with a negative one. However, this effect diminishes with higher levels of income differential. Our results suggest that part of households with negative expected income differentials may fail to optimally cope with aggregate income risks, which may reinforce poverty and inequalities among rural households. Hence the need for policies that reduce vulnerabilities of these households to aggregate risks.

Our model also allows to test how the marginal utility of income changes with child human capital levels, where the school test scores are used as a measure of the child human capital. In the context considered here, we find evidence for a decrease in the household's marginal utility of income following an increase in the child's human capital level, suggesting that households are correlation averse. This result suggests that, considering the framework that we assume in this paper, the best specification of the utility function to consider is the non-separability between the household's earnings and the household's children's human capital. More precisely, the child human capital should be modeled as its monetary equivalent in the household's utility function instead of its measured value. This result also means that, in the case of an agricultural income risk, each additional monetary unit is more enjoyable when children's school test scores are lower. We can, therefore, expect that, if income differential is positive and migration is used as a risk coping strategy, households with lower test scores of children may be more likely to send a parent for migration, compared to households with higher test scores of children.

Our findings raise some interesting questions for future research. We performed our analysis using an aggregate measure of the income riskiness; however, it would be interesting to explore whether idiosyncratic measures of the household income risk have the same effects. Examples of these measures include the variance of the household income (Carroll, 1994; Carroll and Samwick, 1998), the variance of the residuals in the household income regression (Jalan and Ravallion, 2001; Guariglia and Rossi, 2002), or the subjective measures of income uncertainty (see e.g. Guiso et al., 2002; Lusardi, 1997). Our paper is also a first step in looking at how changes in the child human capital level affects the marginal utility of income. We do so using data from rural China and the school test scores as a measure of the child human capital. Further research is needed to validate these results using different samples of children and adopting different measures of the child human capital, notably health measures.

Bibliography

- Agesa, R. U. (2001). Migration and the urban to rural earnings difference: A sample selection approach. *Economic Development and Cultural Change*, 49(4):847–865.
- Al-Kaisi, M., Taylor, S. E., and Elmore, R. W. (2012). Soil moisture conditions and crop water use. *Integrated Crop Management News*, 218.
- Antman, F. M. (2013). The impact of migration on family left behind. In Constant, A. and Zimmermann, K. F., editors, *International Handbook on the Economics of Migration*. Edward Elgar Publishing.
- Askarov, Z. and Doucouliagos, H. (2020). A meta-analysis of the effects of remittances on household education expenditure. *World Development*, 129:104860.
- Azzarri, C. and Zezza, A. (2011). International migration and nutritional outcomes in Tajikistan. *Food Policy*, 36(1):54–70.
- Björkman-Nyqvist, M. (2013). Income shocks and gender gaps in education: Evidence from Uganda. *Journal of Development Economics*, 105:237–253.
- Carroll, C. D. (1994). How does future income affect current consumption? *The Quarterly Journal of Economics*, 109(1):111–147.
- Carroll, C. D. and Samwick, A. A. (1998). How important is precautionary saving? *Review of Economics and Statistics*, 80(3):410–419.
- Chang, H., Dong, X.-y., and MacPhail, F. (2011). Labor migration and time use patterns of the left-behind children and elderly in rural china. *World Development*, 39(12):2199–2210.
- Conger, K. J., Rueter, M. A., and Conger, R. D. (1999). The role of economic pressure in the lives of parents and their adolescents: The family stress model. In Crockett, L. J. and Silbereisen, E., editors, *Negotiating Adolescence in Times of Social Change*, pages 201–223. Cambridge University Press.
- de Bruin, A. and Liu, N. (2020). The urbanization-household gender inequality nexus: Evidence from time allocation in china. *China Economic Review*, 60:101301.
- Dillon, A., Mueller, V., and Salau, S. (2011). Migratory responses to agricultural risk in northern Nigeria. *American Journal of Agricultural Economics*, 93(4):1048–1061.
- Du, Y., Park, A., and Wang, S. (2005). Migration and rural poverty in China. *Journal of comparative economics*, 33(4):688–709.
- Dustmann, C. (2003). Children and return migration. *Journal of population economics*, 16(4):815–830.

- Dustmann, C., Fasani, F., Meng, X., and Minale, L. (2020). Risk attitudes and household migration decisions. *Journal of Human Resources*, pages 1019–10513R1.
- Dustmann, C. and Görlach, J.-S. (2016). The economics of temporary migrations. *Journal of Economic Literature*, 54(1):98–136.
- Dutronc-Postel, P. (2019). *Three essays in applied development economics*. PhD thesis, Paris School of Economics.
- Ehrlich, I. and Becker, G. S. (1972). Market insurance, self-insurance, and self-protection. *Journal of Political Economy*, 80(4):623–648.
- Epstein, L. G. and Tanny, S. M. (1980). Increasing generalized correlation: a definition and some economic consequences. *Canadian Journal of Economics*, pages 16–34.
- Fafchamps, M. (1992). Solidarity networks in preindustrial societies: Rational peasants with a moral economy. *Economic Development and Cultural Change*, 41(1):147–174.
- Giles, J. and Mu, R. (2007). Elderly parent health and the migration decisions of adult children: Evidence from rural China. *Demography*, 44(2):265–288.
- Giles, J. and Yoo, K. (2007). Precautionary behavior, migrant networks, and household consumption decisions: An empirical analysis using household panel data from rural China. *The Review of Economics and Statistics*, 89(3):534–551.
- Guariglia, A. and Rossi, M. (2002). Consumption, habit formation, and precautionary saving: evidence from the british household panel survey. *Oxford Economic Papers*, 54(1):1–19.
- Guiso, L., Jappelli, T., and Pistaferri, L. (2002). An empirical analysis of earnings and employment risk. *Journal of Business & Economic Statistics*, 20(2):241–253.
- Heckman, J. J. (1976). The common structure of statistical models of truncation, sample selection and limited dependent variables and a simple estimator for such models. In *Annals of Economic and Social Measurement*, volume 5, pages 475–492. NBER.
- Jalan, J. and Ravallion, M. (2001). Behavioral responses to risk in rural China. *Journal of Development Economics*, 66(1):23–49.
- Jensen, R. (2000). Agricultural volatility and investments in children. *American Economic Review*, 90(2):399–404.
- Kong, S. T., Meng, X., and Zhang, D. (2010). The global financial crisis and rural–urban migration. In Garnaut, R., Golley, J., and L.Song, editors, *China: The Next Twenty Years of Reform and Development*, pages 241–266. ANU Press.
- Li, H. and Zahniser, S. (2002). The determinants of temporary rural-to-urban migration in china. *Urban studies*, 39(12):2219–2235.
- Lucas, R. E. (1987). Emigration to South Africa’s mines. *American Economic Review*, 77(3):313.
- Lusardi, A. (1997). Precautionary saving and subjective earnings variance. *economics letters*, 57(3):319–326.
- Maccini, S. and Yang, D. (2009). Under the weather: Health, schooling, and economic consequences of early-life rainfall. *American Economic Review*, 99(3):1006–26.

- Macours, K. and Vakis, R. (2010). Seasonal migration and early childhood development. *World Development*, 38(6):857–869.
- Marchiori, L., Maystadt, J.-F., and Schumacher, I. (2012). The impact of weather anomalies on migration in sub-saharan Africa. *Journal of Environmental Economics and Management*, 63(3):355–374.
- Mayer, S. E. (2002). *The influence of parental income on children's outcomes*. Wellington, New Zealand: Knowledge Management Group, Ministry of Social Development.
- McKenzie, D. and Rapoport, H. (2007). Network effects and the dynamics of migration and inequality: theory and evidence from Mexico. *Journal of Development Economics*, 84(1):1–24.
- Meng, X. (2012). Labor market outcomes and reforms in China. *Journal of Economic Perspectives*, 26(4):75–102.
- Meng, X. and Yamauchi, C. (2017). Children of migrants: The cumulative impact of parental migration on children's education and health outcomes in China. *Demography*, 54(5):1677–1714.
- Meyerhoefer, C. D. and Chen, C. (2011). The effect of parental labor migration on children's educational progress in rural China. *Review of Economics of the Household*, 9(3):379–396.
- Morduch, J. (2005). *Consumption smoothing across space: Testing theories of risk-sharing in the ICRISAT study region of South India*. Oxford: Oxford University Press.
- Morten, M. (2019). Temporary migration and endogenous risk sharing in village India. *Journal of Political Economy*, 127(1):1–46.
- Mullan, K., Grosjean, P., and Kontoleon, A. (2011). Land tenure arrangements and rural–urban migration in China. *World Development*, 39(1):123–133.
- Munshi, K. and Rosenzweig, M. (2016). Networks and misallocation: Insurance, migration, and the rural-urban wage gap. *American Economic Review*, 106(1):46–98.
- Myerson, R. (2017). Policy analysis with endogenous migration decisions: The case of left-behind children in China. Available at SSRN 3058134.
- Nakosteen, R. A. and Zimmer, M. (1980). Migration and income: The question of self-selection. *Southern Economic Journal*, pages 840–851.
- National Bureau of Statistics (2020). Statistical communiqué of the people's republic of China on the 2019 national economic and social development. Available at: http://www.stats.gov.cn/english/pressrelease/202002/t20200228_1728917.html.
- Pachauri, R. K. and Reisinger, A. (2008). Climate change 2007. synthesis report. contribution of working groups I, II and III to the fourth assessment report.
- Paxson, C. H. (1992). Using weather variability to estimate the response of savings to transitory income in Thailand. *American Economic Review*, 82(1):15–33.
- Peng, S. (2011). Water resources strategy and agricultural development in China. *Journal of Experimental Botany*, 62(6):1709–1713.
- Puhani, P. (2000). The Heckman correction for sample selection and its critique. *Journal of Economic Surveys*, 14(1):53–68.

- Rey, B. and Rochet, J.-C. (2004). Health and wealth: How do they affect individual preferences? *The Geneva Papers on Risk and Insurance Theory*, 29(1):43–54.
- Roberts, K. D. and Morris, M. D. (2003). Fortune, risk, and remittances: An application of option theory to participation in village-based migration networks. *International Migration Review*, 37(4):1252–1281.
- Rose, E. (2001). Ex ante and ex post labor supply response to risk in a low-income area. *Journal of Development Economics*, 64(2):371–388.
- Rosenzweig, M. R. and Binswanger, H. P. (1992). *Wealth, weather risk, and the composition and profitability of agricultural investments*, volume 1055. World Bank Publications.
- Rosenzweig, M. R. and Stark, O. (1989). Consumption smoothing, migration, and marriage: Evidence from rural India. *Journal of Political Economy*, 97(4):905–926.
- Rozelle, S., Taylor, J. E., and DeBrauw, A. (1999). Migration, remittances, and agricultural productivity in China. *American Economic Review*, 89(2):287–291.
- Stark, O. and Levhari, D. (1982). On migration and risk in LDCs. *Economic Development and Cultural Change*, 31(1):191–196.
- Stark, O. and Taylor, J. E. (1991). Migration incentives, migration types: The role of relative deprivation. *The Economic Journal*, 101(408):1163–1178.
- Taylor, J. E. and Lopez-Feldman, A. (2010). Does migration make rural households more productive? Evidence from Mexico. *Journal of Development Studies*, 46(1):68–90.
- Taylor, J. E., Rozelle, S., and De Brauw, A. (2003). Migration and incomes in source communities: A new economics of migration perspective from China. *Economic Development and Cultural Change*, 52(1):75–101.
- Todaro, M. P. (1969). A model of labor migration and urban unemployment in less developed countries. *American Economic Review*, 59(1):138–148.
- Townsend, R. M. (1994). Risk and insurance in village India. *Econometrica*, 62(3):539–591.
- Tsegai, D. (2007). Migration as a household decision: What are the roles of income differences? insights from the volta basin of Ghana. *The European journal of development research*, 19(2):305–326.
- Udry, C. (1994). Risk and insurance in a rural credit market: An empirical investigation in northern Nigeria. *The Review of Economic Studies*, 61(3):495–526.
- UNICEF (2018). Country office annual report 2018, China. Available at: https://www.unicef.org/about/annualreport/files/China_2018_COAR.pdf.
- Zhao, G. (2015). Can money ‘buy’ schooling achievement? Evidence from 19 Chinese cities. *China Economic Review*, 35:83–104.
- Zhao, L., Liu, S., and Zhang, W. (2018). New trends in internal migration in China: Profiles of the new-generation migrants. *China & World Economy*, 26(1):18–41.
- Zheng, J. and Newman, J. (1986). The climatic resources for wheat production in China. *Agricultural and forest meteorology*, 38(1-3):205–216.

Zhu, N. (2002). The impacts of income gaps on migration decisions in China. *China Economic Review*, 13(2-3):213-230.

Appendix

2.A Theoretical model

2.A.1 Functional forms of the utility function

The household's correlation aversion, i.e. how the marginal utility of income varies with respect to the level of child human capital, given by $u^{(1,1)}$, allows to determine which functional form of this utility function is to be used.

If the household is assumed to be correlation neutral ($u^{(1,1)} = 0$), then the additive separability between the household's earnings and the child's human capital should be assumed ($u(y, z) = \mu(y) + \nu(z)$ with $\mu' > 0$, $\mu'' < 0$, $\nu' > 0$ and $\nu'' < 0$).^{40 41}

If the household is correlation averse ($u^{(1,1)} < 0$), we are assuming the non-separable form of the utility function ($u(y, z) = \mu(y + f(z))$ with $\mu' > 0$, $\mu'' < 0$, $f' > 0$ and $f'' < 0$, where $f(z)$ is the monetary equivalent of the child's human capital level z).

Finally, if the household is correlation loving ($u^{(1,1)} > 0$), we can then consider the multiplicative separability between the household's earnings and the child's human capital ($u(y, Z) = \mu(y)\nu(Z)$ with $\mu' > 0$, $\mu'' < 0$, $\nu' > 0$ and $\nu'' < 0$).

2.A.2 Probability of migration

Using a Taylor expansion of order 2 around (Y_0, Z_0) , we obtain:

$$\begin{aligned} u(Y_0 + \hat{\Delta}_y, Z_0 + \hat{\Delta}_z) &\sim u(Y_0, Z_0) + \hat{\Delta}_y u^{(1,0)}(Y_0, Z_0) + \hat{\Delta}_z u^{(0,1)}(Y_0, Z_0) \\ &\quad + \frac{1}{2}(\hat{\Delta}_y)^2 u^{(2,0)}(Y_0, Z_0) + \frac{1}{2}(\hat{\Delta}_z)^2 u^{(0,2)}(Y_0, Z_0) + \hat{\Delta}_y \hat{\Delta}_z u^{(1,1)}(Y_0, Z_0). \end{aligned}$$

⁴⁰Let $h(x)$ denote a one-attribute differentiable function. $h'(x)$ and $h''(x)$ denote, respectively, the first and second derivatives of h .

⁴¹ $\nu(z)$ can be written as $\delta v(Z)$ where δ is a parameter that refers to the household's degree of altruism toward the child.

Using our assumptions, ΔU (i.e. $u(Y_0 + \hat{\Delta}_y, Z_0 + \hat{\Delta}_z) - u(Y_0, Z_0)$) can be approximated by

$$\Delta U \sim \hat{\Delta}_y u^{(1,0)} + \hat{\Delta}_z u^{(0,1)} + \frac{1}{2}(\hat{\Delta}_y)^2 u^{(2,0)} + \frac{1}{2}(\hat{\Delta}_z)^2 u^{(0,2)} + \hat{\Delta}_y \hat{\Delta}_z u^{(1,1)}.$$

The probability of migration, q is such that:

$$\begin{aligned} q &= p(\Delta U \geq \hat{\alpha}) \\ \Leftrightarrow q &= p(\epsilon \leq -\beta_0 X + \Delta U) \\ \Leftrightarrow q &= F[-\beta_0 X + \Delta U] \\ \Leftrightarrow q &= F[\beta_1 \hat{\Delta}_y + \beta_2 \hat{\Delta}_y^2 + \beta_3 \hat{\Delta}_z + \beta_4 \hat{\Delta}_z^2 + \beta_5 \hat{\Delta}_y \hat{\Delta}_z - \beta_6 X] \\ \text{with } \beta_1 &= u^{(1,0)}, \beta_2 = \frac{1}{2}u^{(2,0)}, \beta_3 = u^{(0,1)}, \beta_4 = \frac{1}{2}u^{(0,2)}, \beta_5 = u^{(1,1)}. \end{aligned}$$

2.B Rainfall and agriculture in China

There are two types of farming in China: rain-fed farming which depends only on natural rainfall, and irrigated farming where irrigation water is used in addition to the rainwater. For the latter, rainwater contributes to more than half of the needed water. Hence, in 2007 about 57% of the total available water for agricultural use in China was from rainfall while only about 43% was from irrigation water. Breaking down these values for the different regions of China shows that, except for the Northwest areas, more than 50% of agricultural water used in all regions comes from precipitation. Part of this is also linked to the fact that farmers usually do not fully benefit from the irrigation water supplied to them. According to a report by the Ministry of Water Resources, up to 55% of irrigation water is wasted during delivery before reaching its final point.

Given the large dependence of agricultural production to rainfall water, droughts are among the biggest problems for agricultural production in China, especially in areas with limited irrigation systems such as the North-East and the North-West. Droughts unavoidably result in considerable reductions of the grain production, up to 150 million kg per year. Corn production, for instance, can be reduced to as much as 20-50% of potential yield when comparing wet and drought years (Peng, 2011). As a result, optimal yields highly depend on the distribution of precipitation and the available soil moisture during the growth, flowering and filling stages of crops (Zheng and Newman, 1986).

Table 2.B.1 highlights the most important crops for each of the surveyed provinces and shows that the main crops to consider are rice, wheat, corn, soybeans and tubers. Rice is the most prevalent grain crop in China. It can be grown as a single or a double-season cropping system. The major region which produces rice is Southern China, including six of the provinces in our sample (Jiangsu, Zhejiang, Anhui, Hubei, Guangdong and

Sichuan). These provinces account for about 40% of China's production of rice. Winter wheat, which accounts for more than 90% of the total wheat production in China, is mainly grown in Northeastern China, including 5 of the provinces in this study (Hebei, Jiangsu, Anhui, Henan and Hubei). These provinces account for about 53% of the wheat production of the country. Finally, corn is mainly planted in North, Central and hilly South-West China. It is a major crop in one of our provinces: Hebei that produces about 10% of the total country corn production. Since Hebei is a Northeastern region, the main corn production is a spring corn.⁴²

Table 2.B.1: The Highest production of grain crops for each Province

Province	Highest production	Second highest production
Hebei	Corn	Wheat
Jiangsu	Rice	Wheat
Zhejiang	Rice	Soybeans
Anhui	Rice	Wheat
Henan	Wheat	Corn
Hubei	Rice	Wheat
Guangdong	Rice	Tubers
Chongqing	Tubers	Rice
Sichuan	Rice	Tubers

Source: China Statistical Yearbook 2007 (Values for 2006).

According to the Food and Agriculture Organization (FAO), water is needed more for grown crops than for crops that were just planted.⁴³ The water need at planting stage is evaluated at 50% of the crop water need during the mid-season stage. It starts to increase during the crop development stage and reaches its maximum at the beginning of the mid-season stage. For the dry harvested crops that we consider in this study, the water need is minimal during the late season stage when crops mature and are harvested). Relying on this information, we determine for each major crop in our study the most important months for crop production in the surveyed areas. We infer that March, April and May are important months for winter wheat, April, May and June for early rice, August, September and October for late rice, June, July and August for single rice, corn and soybeans. It follows that rainfall for March-October is the most important in determining the success of the different important crops in the provinces considered in our sample. Moreover, soil moisture is crucial during the growing season, in order to get an optimal crop. It is available as stored water in the soil or by instant rainfall (Al-Kaisi et al.,

⁴²The percentages that appear in this paragraph are based on the China Statistical Yearbook (2007)

⁴³<http://www.fao.org/docrep/s2022e/s2022e02.htmTopOfPage>.

2012). The moisture and temperature sensitive months for the different crops we consider (April-September) are included in this period of March-October.

2.C Data analysis

Table 2.C.1: Definition of variables

Variable name	Definition
<i>Household characteristics</i>	
Migrant parent	1 = household has a migrant parent
Number of migrants	Number of household members migrating
Household income	Logarithm of the total household income
Income differential	Expected difference in log of household income between migrant household and non-migrant household, when faced with an income risk
Child human capital differential	Expected difference in child human capital between migrant household and non-migrant household, when faced with an income risk
Mean age	Average age of the household labor force members
Mean schooling	Average years of education of the household labor force members
Male headed	1 = household head is male
Household size	Number of household members (including migrants)
Ethnic household	1 = household belongs to an ethnic minority
Preschool children	Number of children in household aged < 6
School children (age<16)	Number of children in household aged > 5 and < 16 and at school
School children (age>=16)	Number of children in household aged > 15 and at school
Number of female adults (>15)	Number of household females aged > 15
Number of male adults (>15)	Number of household males aged > 15
Gender ratio	Ratio of males over the household labor force
Labor ratio	Ratio of the household labor force over the household size
Elderly (>60)	Number of household members over 60 years
Disabled	Number of household members with a disability or that have lost their work ability (aged <= 60)
Land size	Household farm land size
Irrigated land	Household effective irrigation area
House value	Estimated market present value of self-owned housing
Access to formal credit	1 = household applied for a loan from financial organizations, or did not but guessed would be approved if they did
Access to informal credit	1 = household borrowed money from private lenders, or did not but guessed would be able to if they did
<i>Child characteristics</i>	
Math score	Standardized mathematics' final exam score of the last school term
Chinese score	Standardized Chinese's final exam score of the last school term
Age	Child's age
Male	1 = the child is male
Eldest Child	1 = the child is the eldest among siblings
One sibling	1 = the child has one sibling
No sibling	1 = the child has no siblings
Parents' years of schooling	The average years of education of the child's parents
<i>Village characteristics</i>	
Primary school in the village	1 = village has a standard six-grade primary school, other kind of primary school or a teaching spot
Unified irrigation system	1 = the village provides a unified drainage and irrigation system
Furrow machine	1 = the village provides a furrow machine
Plant disease prevention and treatment	1 = the village implements united plant diseases and insect prevention and treatment
United purchasing service	1 = the village provides a united production material purchasing service
Share of village migrant (2005)	Number of village labor migrants in 2005 over the village population in 2007
Village Labor out	1 = the village collective organizes labor, finding jobs outside the village in 2008
<i>Regional characteristics</i>	
East	1= household lives in Hebei, Jiangsu, Zhejiang or Guangdong provinces
Center	1= household lives in Henan, Hubei or Anhui provinces
West	1= household lives in Chongqing municipality or Sichuan province
<i>Risk variables</i>	
Rainfall Coefficient of Variation (Mar-Oct)	The ratio of the standard deviation and the mean of rainfall during the months of March to October of 2008

Table 2.C.2: Test for attrition bias

	Included in the final sample
Number of migrants	-1.345*** (0.047)
Household income	0.228*** (0.044)
Mean Age	0.006 (0.005)
Mean schooling	-0.010 (0.015)
Male headed	0.036 (0.131)
Household size	-0.221*** (0.044)
Preschool children	0.163 (0.107)
School children (age<16)	0.310*** (0.093)
School children (age>=16)	-0.135 (0.102)
Gender ratio	0.000 (0.002)
Labor ratio	-0.012*** (0.004)
Land size	0.006 (0.006)
Irrigated land	0.000 (0.001)
House value	-0.027 (0.023)
Eldery (>60)	0.080 (0.063)
Disabled	0.015 (0.131)
Province fixed effects	Yes
Observations	3652

Notes: "Included in the final sample"=1 if the household is included in our final sample. Regressors are defined in Table 2.C.1. Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 2.C.3: Summary statistics by migration status, 2008

	(1)	(2)	(3)	(4)
<i>Household characteristics</i>				
Household size 08	4.15 (1.09)	4.14 (1.10)	4.23 (1.05)	-0.09
Mean Age 08	41.39 (6.70)	41.42 (6.82)	41.24 (6.09)	0.19
Mean schooling (2008)	7.32 (2.02)	7.36 (2.05)	7.08 (1.88)	0.29**
Male headed	0.96 (0.19)	0.96 (0.19)	0.95 (0.22)	0.01
Gender ratio (2008)	49.48 (10.99)	49.31 (11.35)	50.32 (8.99)	-1.01
% of females aged >16	37.35 (13.22)	37.73 (13.34)	35.48 (12.49)	2.25***
% of males aged >16	36.19 (13.96)	36.33 (14.02)	35.51 (13.66)	0.83
Labor ratio (2008)	60.40 (12.43)	60.66 (12.48)	59.13 (12.14)	1.52**
Ethnic household	0.08 (0.27)	0.08 (0.27)	0.08 (0.28)	-0.00
% of children aged <6	2.73 (7.46)	2.52 (7.22)	3.76 (8.46)	-1.24***
% of school children aged 6-15	23.68 (16.30)	23.36 (16.44)	25.26 (15.49)	-1.90**
% of school children aged >16	10.58 (15.18)	10.91 (15.24)	8.94 (14.83)	1.96**
% of household members aged >=60	6.39 (12.34)	6.14 (12.13)	7.62 (13.28)	-1.47**
Land size	4.57 (5.12)	4.59 (5.41)	4.46 (3.37)	0.12
% of the irrigated land	75.17 (33.92)	75.73 (34.06)	72.52 (33.14)	3.21*
House value	77743 (181477)	83525 (195946)	49166 (70646)	34359***
Access to formal credit	0.80 (0.40)	0.80 (0.40)	0.78 (0.41)	0.02
Access to informal credit	0.92 (0.26)	0.92 (0.26)	0.92 (0.27)	0.00
Migrant Parent	0.17 (0.37)	0.00 (0.00)	1.00 (0.00)	-1.00
<i>Regional characteristics</i>				
East	0.45 (0.50)	0.46 (0.50)	0.37 (0.48)	0.09***
Center	0.37 (0.48)	0.37 (0.48)	0.37 (0.48)	-0.00
West	0.18 (0.39)	0.17 (0.37)	0.25 (0.44)	-0.08***
Observations	2268	1888	380	2268

Notes: This table reports means of household and regional characteristics of all households (Column (1)), households with no migrants (column (2)) and households with one migrating parent (Column (3)). *Mu* is the Chinese measurement of land. 1 Hectare = 15 *Mu*. This table uses the sample where only one parent may be a migrant. Standard deviations are in parentheses. Column (4) tests for differences in means between the two types of households. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 2.C.4: Summary statistics by migration status - Income variables, 2008

	(1)	(2)	(3)	(4)
Total net income	22950 (17818)	23588 (17896)	19778 (17098)	3811***
Net income from wages	10164 (12515)	9667 (11590)	12632 (16148)	-2964***
<i>of which:</i> Net wage income from local off-farm	5696 (9527)	6459 (10100)	1906 (4212)	4554***
<i>of which:</i> Net wage income from migrants	3386 (8373)	1967 (4773)	10436 (15686)	-8469***
Net income from family farm operation	7888 (13406)	8396 (14489)	5363 (4703)	3033***
Net income from family off-farm operation	3322 (9279)	3851 (9957)	690 (3615)	3161***
Net property income	587 (2253)	670 (2431)	174 (862)	496***
Net transfer income	990 (2622)	1004 (2623)	919 (2622)	85
Observations	2268	1888	380	2268

Notes: This table reports means of income components of all households (Column (1)), of households with no migrants (column (2)) and of households with one migrating parent (Column (3)). This table uses the sample where only one parent may be a migrant. Standard deviations are in parentheses. Column (4) tests for differences in means between the two types of households. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 2.C.5: Summary statistics by migration status - Child characteristics, 2008

	(1)	(2)	(3)	(4)
Math score	81.17 (12.32)	81.42 (12.09)	79.93 (13.35)	1.49**
Chinese score	79.47 (12.33)	79.69 (12.29)	78.42 (12.48)	1.27**
Age	13.24 (3.90)	13.32 (3.93)	12.83 (3.69)	0.50***
Male	0.53 (0.50)	0.53 (0.50)	0.53 (0.50)	0.01
Number of siblings	0.89 (0.85)	0.90 (0.88)	0.82 (0.69)	0.08*
Mother's years of schooling	7.28 (2.23)	7.33 (2.23)	7.03 (2.20)	0.30***
Father's years of schooling	8.23 (2.15)	8.27 (2.20)	8.06 (1.84)	0.21**
number hours studying	9.09 (6.71)	9.22 (6.84)	8.49 (6.09)	0.73*
Observations	3061	2544	517	3061

Notes: This table reports means of child characteristics of all households (Column (1)), of households with no migrants (column (2)) and of households with one migrating parent (Column (3)). This table uses all children from each household in the sample where only one parent may be a migrant. Standard deviations are in parentheses. Column (4) tests for differences in means between the two types of households. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 2.C.6: Estimates of the structural model of migration (alternative migration duration)

	(1)	(2)	(3)	(4)	(5)	(6)
A. Migrant parent for at least 3 months						
<i>Expected changes</i>						
Income differential	1.236** (0.559)	1.198** (0.528)	1.189** (0.559)	1.148** (0.536)	1.306** (0.555)	1.261** (0.518)
Income differential ²	-3.413*** (1.164)	-2.418 (1.650)	-3.404*** (1.166)	-2.443 (1.653)	-3.415*** (1.160)	-2.390 (1.638)
Child human capital differential	0.077* (0.042)	0.311*** (0.033)	0.082* (0.042)	0.301*** (0.033)	0.073* (0.042)	0.319*** (0.033)
Child human capital differential ²	-0.012*** (0.003)	-0.021*** (0.005)	-0.011*** (0.003)	-0.020*** (0.005)	-0.013*** (0.004)	-0.021*** (0.005)
Interaction	-0.100 (0.080)	-0.239* (0.125)	-0.103 (0.079)	-0.238** (0.120)	-0.094 (0.081)	-0.236* (0.128)
Observations	1717	1717	1717	1717	1717	1717
B. Migrant parent for at least 9 months						
<i>Expected changes</i>						
Income differential	1.272 (1.213)	-0.390 (0.797)	1.130 (1.207)	-0.405 (0.827)	1.356 (1.198)	-0.308 (0.737)
Income differential ²	-3.302*** (1.215)	-1.389 (1.040)	-3.208*** (1.200)	-1.492 (1.039)	-3.367*** (1.222)	-1.334 (1.030)
Child human capital differential	-0.652*** (0.085)	0.227*** (0.053)	-0.632*** (0.080)	0.215*** (0.053)	-0.651*** (0.086)	0.215*** (0.047)
Child human capital differential ²	-0.017*** (0.003)	-0.000 (0.003)	-0.016*** (0.002)	-0.000 (0.002)	-0.017*** (0.003)	0.000 (0.002)
Interaction	0.028 (0.080)	0.009 (0.069)	0.018 (0.078)	0.006 (0.070)	0.035 (0.080)	0.010 (0.064)
Observations	1837	1837	1837	1837	1837	1837
Household Characteristics	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table reports regression coefficients from 12 separate regressions. The outcome in panel A is a dummy variable that equals 1 if only one parent is a migrant for at least 3 months and 0 otherwise, while the outcome in panel B is a dummy variable that equals 1 if only one parent is a migrant for at least 9 months and 0 otherwise. See notes to Table 2.5.1.

Table 2.C.7: Estimates of the structural model of migration: full specification

	(1)	(2)	(3)	(4)	(5)	(6)
<i>Expected changes</i>						
Income differential	1.878*** (0.574)	1.442** (0.638)	1.767*** (0.576)	1.318** (0.648)	1.998*** (0.562)	1.553** (0.608)
Income differential ²	-3.158*** (1.204)	-3.479** (1.687)	-3.215*** (1.204)	-3.573** (1.693)	-3.071** (1.200)	-3.315** (1.652)
Child human capital differential	0.122*** (0.033)	0.345*** (0.036)	0.121*** (0.032)	0.338*** (0.037)	0.123*** (0.033)	0.348*** (0.034)
Child human capital differential ²	-0.008*** (0.002)	-0.014*** (0.004)	-0.007*** (0.002)	-0.013*** (0.004)	-0.008*** (0.003)	-0.014*** (0.004)
Interaction	-0.090 (0.071)	-0.194* (0.109)	-0.103 (0.070)	-0.220** (0.107)	-0.074 (0.071)	-0.171 (0.109)
<i>Household characteristics</i>						
Land size	-0.085*** (0.013)	0.056*** (0.017)	-0.083*** (0.013)	0.055*** (0.016)	-0.086*** (0.013)	0.051*** (0.017)
Mean Age	0.146** (0.071)	0.164* (0.097)	0.155** (0.070)	0.186** (0.095)	0.135* (0.071)	0.133 (0.097)
Mean age ²	-0.002** (0.001)	-0.002* (0.001)	-0.002** (0.001)	-0.002* (0.001)	-0.002* (0.001)	-0.002 (0.001)
Mean schooling (2007)	-0.129*** (0.026)	-0.338*** (0.048)	-0.125*** (0.026)	-0.327*** (0.046)	-0.128*** (0.026)	-0.333*** (0.048)
Gender ratio	0.025*** (0.004)	0.060*** (0.011)	0.025*** (0.004)	0.058*** (0.010)	0.025*** (0.004)	0.061*** (0.011)
Labor ratio	0.002 (0.007)	0.019 (0.012)	0.001 (0.007)	0.015 (0.012)	0.004 (0.007)	0.022* (0.013)
Household size	-0.153* (0.084)	-0.840*** (0.152)	-0.158* (0.083)	-0.830*** (0.145)	-0.150* (0.085)	-0.813*** (0.153)
Preschool children	0.604*** (0.209)	1.453*** (0.352)	0.611*** (0.206)	1.434*** (0.331)	0.591*** (0.212)	1.398*** (0.361)
School children (age<16)	0.112 (0.173)	0.802*** (0.289)	0.201 (0.172)	0.972*** (0.279)	0.036 (0.174)	0.603** (0.295)
School children (age>=16)	0.428** (0.198)	0.716** (0.324)	0.490** (0.198)	0.820*** (0.316)	0.365* (0.198)	0.589* (0.330)
Eldery (>60)	-0.030 (0.127)	0.269 (0.188)	-0.030 (0.127)	0.242 (0.183)	-0.023 (0.126)	0.273 (0.189)
Disabled	-0.338 (0.276)	-0.731 (0.536)	-0.344 (0.277)	-0.772 (0.552)	-0.325 (0.271)	-0.675 (0.500)
<i>Instruments</i>						
Share of village migrant (2005)	0.342* (0.208)	0.990*** (0.250)	0.345* (0.206)	0.967*** (0.245)	0.349* (0.208)	1.002*** (0.247)
Village Labor out	0.459*** (0.110)	0.834*** (0.160)	0.465*** (0.110)	0.849*** (0.154)	0.450*** (0.110)	0.820*** (0.162)
Observations	1767	1767	1767	1767	1767	1767

Notes: This table reports regression coefficients from 6 separate regressions, using the sample where only one parent is a migrant. See notes to Table 2.5.1.

Chapter 3

Long-Term Effects of Environmental Policies on Educational Performance: Evidence from China

3.1 Introduction

Human capital is shown to have an important role in determining labor market outcomes (Heckman et al., 2006) and as a driver of long-term economic growth (Schultz, 1961; Romer, 1986). Its importance may, in part, explain why governments allocate an average of 4.5% of their GDP for education (The World Bank, 2017), and why Chinese families spent in 2017 alone, an average of 21.6% of their total disposable income on private tutoring (Guo et al., 2020). However, human capital formation depends on many factors, other than monetary investments. These factors include, according to the “fetal origins” hypothesis and its extension into early childhood environment, in-uterus and early-life health conditions and shocks (Almond et al., 2018).

In this paper, we investigate how a health shock, induced by an environmental regulation, over which authorities have full control, can affect long-term development of human capital.¹ Two channels may be in place. One through improvements of air quality induced by the environmental policy, while the other may be through changes in parental earnings if the later interfere with early-childhood parental investments.² Moreover, in addition to

¹Most of early-life health shocks considered in the literature are difficult to predict or to avoid. For example, Almond et al. (2010) examined, in China, the effect of prenatal exposure to the 1959-1961 famine on the likelihood of being illiterate as an adult.

²Parental investments are shown to determine the formation of both noncognitive and cognitive skills (Cunha and Heckman, 2008).

their direct impact on human capital outcomes, the potential effects of an environmental policy may also work as reinforcement to other investments throughout the childhood, by the potentially dynamic complementarities in human capital accumulation (Cunha and Heckman, 2007).³

In recent decades, China has witnessed a rapid urbanization and industrialization processes. This accelerated development of its economy has been associated with increasing ambient air pollution levels, raising concerns about the negative consequences on public health (Deng et al., 2015; Chen et al., 2017a), happiness and life satisfaction (Zhang et al., 2017; Zheng et al., 2019) and the economic activity (Chang et al., 2019; He et al., 2019; Li and Zhang, 2019).⁴ In an attempt to control the high levels of pollutants' emissions and, particularly, the Sulfur dioxide (SO₂), the Chinese government implemented, in 1998, the Two Control Zones (TCZ) policy. The later imposed stringent environmental restrictions in various locations exceeding nationally mandated pollution standards. In this paper, we focus on the TCZ policy and investigate how it affected long-term educational performance, measured 15 years later, of those exposed to the effects of its implementation in their year of birth (in utero and first year of birth). Moreover, we compare the effects of exposure to the TCZ policy between older and younger children, at the time of its implementation. This question is of clear policy relevance. Additional measures may be needed for the age-group gaining less from the environmental policy, in order to reinforce its initial benefits. Finally, even though we focus on the overall effect of the TCZ environmental policy on long-term education outcomes, inclusive of any possible channel, we examine its particular effect that goes through the impact on air quality.

To carry out our analysis, we draw individual data from the fifth wave survey of the China Household Income Project (2013) and focus on three measures of educational performance at the age of 15. One challenge of our empirical design is the non-randomness in the assignment of the TCZ designation. However, we show that most of the observable characteristics of the TCZ and non-TCZ counties follow the same trends in the pre-TCZ period, suggesting that the TCZ status is less likely to be confounded by differential trends in unobservable characteristics. Our main results show positive and significant effects of exposure to the TCZ policy, in one's year of birth, on children's long-term educational outcomes, 15 years later. Particularly, we find that, in the absence of the TCZ policy,

³"If investment inputs are not perfect substitutes but are instead complements, government investment in the early years for disadvantaged children promotes investment in the later years." Cunha and Heckman (2008).

⁴One important reason of the high levels of air pollution in China is the heavy reliance on coal as its primary source of energy. Since 1990 and until 2015, coal accounted for more than 72% of the energy produced in China (NBS of China, 2019).

individuals born in counties designated as TCZ would have been less likely to obtain high high school entrance exam scores and therefore, less likely to attend a high quality high school. They would have also been less likely to choose an academic high school, instead of a specialized/technical one which focuses on manual labor training. Results from our correlated random effects specification indicate that exposure to the TCZ policy, between conception and age 1, is associated with a 12.5 percentage point increase in the probability to join a higher quality high school and an 18.7 percentage point increase in the probability to join an academic high school. Projecting forward, we also suggest better future higher education and labor market outcomes, stemming from being able to attend academic and better quality high schools. Moreover, we find that important benefits associated with the TCZ policy relate to girls and to children born to low educated fathers. These results suggest that the environmental regulations may be used as a possible mechanism to reduce disparities in educational performance. However, we find no differential impacts between children exposed to the TCZ policy implementation at ages 1-5, in terms of the probability to attend a higher quality high school or an academic high school, although that does not imply the absence of positive effects for these age cohorts. In the case of beneficial effects at these slightly older ages, it suggests that the benefits of exposure to the TCZ policy are larger than the ones studied here, including a wider age-group during early-life.

This paper contributes to the previous literature in three different ways. First, we add to the literature relating early-life pollution exposure to long-term human capital outcomes, particularly educational outcomes. Few studies assessed this effect in the developing world context (Bharadwaj et al., 2017; Rosales-Rueda and Triyana, 2019; Molina, 2021).⁵ We further this research by considering the persistent effects of exposure to another common pollutant, the Sulfur dioxide (SO_2), on long-term educational performance outcomes. Moreover, previous studies on the relationship between air quality and education in China have almost exclusively focused on the short term effects of air pollution.⁶ No study, to our knowledge, has examined how the air quality effects may persist in the long term, in the Chinese context.

⁵Molina (2021) showed that in utero exposure to thermal inversions leads to lower adult cognitive abilities in Mexico, while Bharadwaj et al. (2017) reported that fetal exposure to carbon monoxide (CO) and particulate matter (PM_{10}) has a negative effect on fourth grade test scores in Chile. However, Rosales-Rueda and Triyana (2019) found no apparent significant effect of in utero exposure to air pollution on children's cognitive function in Indonesia, while Shrestha (2019) suggested that air pollution lowered cognitive test scores in the same country.

⁶Examples include Zivin et al. (2020) who investigated the contemporaneous impacts of fires on the National College Entrance Examination (NCEE) scores of exposed individuals. Chen et al. (2017c) and Zhang et al. (2018) also studied the short-term effects of exposure to air pollution on cognitive performance using cognitive test scores.

Second, this paper contributes to an even smaller body of research that investigates the overall long-term effects of environmental regulations on educational performance (Nilsson, 2009; Isen et al., 2017). Isen et al. (2017) reported the existence of a relationship between the Clean Air Act (CAA) of 1970 and later-life earnings, suggesting that this effect may have operated, in part, through the effects on total years of schooling in the United States. Nilsson (2009), however, exploited geographical variation in air lead levels, induced by the gasoline lead level regulations by the Swedish government, to investigate the effect of reduced early childhood lead exposure on long-run education outcomes. These studies have focused on developed countries, where pollution levels are considered relatively small compared to that of China,⁷ and where children are enjoying different social and economic conditions.⁸ In case of non-linear relationships between air quality or parental economic conditions and long-term educational outcomes, the marginal effects may depend on their initial values. Therefore, it may be misleading to rely on developed countries' studies to predict the effects of air pollution regulations in a developing country setting. No study, to the best of our knowledge, has investigated the long-term effects of early-life exposure to an environmental regulation, in a developing country context. We are providing, therefore, an additional empirical support for the "fetal origins" hypothesis and its extension into the early-life determinants of long-run outcomes, by examining, in China, the long-run effects of the TCZ policy.

Finally, several studies documented the TCZ policy's different economic costs for the country.⁹ Investigating its benefits and showing its effectiveness compared to its costs will, therefore, be helpful in maintaining and motivating the implementation of such environmental regulations in the developing world. Tanaka (2015) showed the contemporaneous improvements in infant health, inducing a reduction in infant mortality, following the TCZ policy implementation. However, focusing on short-term gains may underestimate the true total benefits of an environmental policy, particularly since some effects, such as the effects on mental development, may first become apparent only later on. We show, in this paper, how the TCZ policy might improve long-term mental and cognitive ability development for the surviving cohorts.

The remainder of the paper is structured as follows. Section 2 presents the TCZ

⁷For example, in 1995, in China, the total suspended particulates level exceeded by four times that of the United States in 1970, the year when the CAA was amended (Tanaka, 2015).

⁸In the 1990s, China's poverty population was determined to be around 260 million (Angang et al., 2005). While, in 1993, the number of poor Americans was determined to be 39.3 million, before falling throughout the decade to 31.6 million in 2000 (Chaudry et al., 2016).

⁹These costs include a decrease in sectoral exports in targeted locations (Hering and Poncet, 2014), hindrance of firm productivity (Tang et al., 2020) and a fall in foreign direct investment (Cai et al., 2016).

policy's background and implementation. Section 3 suggests a conceptual framework describing the relationship between the environmental policy and educational outcomes. Empirical models are detailed in Section 4. Section 5 describes the data, and results are presented in Section 6. Section 7 provides some robustness checks, and Section 8 concludes.

3.2 The Two Control Zones policy

Alongside years of China's fast economic growth, air pollution increased to levels harmful to human health. For example, total SO₂ emissions went from 18.4 million tons in 1990 to 23.7 million tons in 1995 (SEPA, 1996). In response, the Chinese government developed a number of environmental regulatory laws and policies. One of them is the Air Pollution Prevention and Control Law of the People's Republic of China (APPCL), enacted in 1987, and amended in 1995 in order to include a section about the regulation of pollutant emissions and coal combustion (Hao et al., 2007). However, the 1995 APPCL was poorly enforced and had low efficacy in reducing air pollution, leading to the proposition of a new regional scheme, the so-called Two Control Zone policy. The later was approved and put into effect in January of 1998 (State Council, 1998).

Criteria Targeted locations of the TCZ policy were chosen based on the records of acid rain and sulfur dioxide from previous years.¹⁰ Particularly, a location was designated as SO₂ pollution control zone if (1) the average annual ambient SO₂ concentrations had been higher than the national Class II standard (i.e. $60\mu\text{g}/\text{m}^3$), (2) the daily average concentrations of SO₂ had been larger than the Class III standard (i.e. $100\mu\text{g}/\text{m}^3$), or (3) the SO₂ emissions were important. A location was designated as acid rain control zone if (1) the average annual precipitation's pH values were equal to or less than 4.5, (2) the Sulfate deposition exceeded the critical load, or (3) the SO₂ emissions were significant. Areas designated as TCZ, at the second or the third administrative level, are reported in a document, published by the State Council, known as the "Official Reply to the State Council Concerning Acid Rain Control Areas and Sulfur Dioxide Pollution Control Areas".¹¹ Particularly, among 333 prefecture cities across 27 provinces in China, 175 were labeled as TCZ which, according to Hao et al. (2001), accounted for 11.4% of China's territory, 40.6% of its population, 62.4% of its GDP, and 58.9% of its total SO₂ emissions

¹⁰The exact years are not specified in the original document.

¹¹China has four formal administrative levels, which, classified from the highest to the lowest, are: provinces/autonomous regions/municipalities, prefectures/prefecture-level cities, counties/county-level cities/districts and townships/towns/sub-districts.

in 1995. Geographically, the acid rain control zones are concentrated in the south, while SO₂ pollution control areas are mainly located in the north (see Figure 3.A.1).

Enforcement The TCZ policy has set several measures that limit the use and production of high-sulfur coal and promote the establishment of clean coal technology (see e.g., Hao et al., 2001). The establishment of the National Environmental Protection Bureau (NEPB) and the limited influence of local governments in setting the policy directives, for their own cities, reduce the concern about having biased results due to poorly implemented policy.

Effectiveness The TCZ regulatory actions were proven effective in reducing pollution emissions at the national level (see e.g., Hao et al. 2001; Yang et al. 2002). However, air pollution and acid rain fell substantially more in the designated TCZ locations. For example, the number of cities, among TCZ cities, reaching the SO₂ concentration standards (i.e. the Class II standard) rose from 81 in 1997 to 93 in 1998 and to 98 in 1999 (He et al., 2002). The SO₂ emissions also dropped by about 3 million tons in the TCZ locations, with about 71% of factories, emitting more than 100 tons of pollutants per year, decreased their SO₂ emissions to the standard between 1998 and 2000 (He et al., 2002). This translated into a substantial fall of pollution emissions and improved overall air quality in TCZ locations.

3.3 Conceptual framework

In this section, we explore the possible channels through which the TCZ policy may have affected long-term human capital formation.

The first channel concerns changes in air quality, which itself can affect long-term outcomes in two different ways. First, damage to neurological development and physical health from early-life exposure to air pollution is biologically plausible. The reduced oxygen or cellular and organ damages suffered by the exposed mother may result in lower nutrition and oxygen flows to the fetus, directly impairing the brain development (Sunyer and Dadvand, 2019).¹²¹³ Such factors may even provoke a number of physical problems, such as a shorter gestation period or a low weight at birth (Dejmek et al., 1999; Liu et al., 2019). The later was shown to have long-term effects on different outcomes, including IQ and education (McCormick et al., 1996; Black et al., 2007), poorer language and social

¹²As the brain development of the fetus may start since week four and continue even after birth, the longer the exposure of the mother during this period to air pollution, the bigger the potential damage to the brain may be.

¹³In animal models, prenatal exposure to air pollution modifies brain development, generally causing long-term problems in functions associated with memory systems (Brockmeyer and d'Angiulli, 2016).

skills (Hack et al., 1992), and behavioral problems such as increased attention deficit (Pharoah et al., 1994). Pollutants do not affect the fetal development only through their effect on the mother's health but, can also directly migrate to the fetus' system through the bloodstream, causing potential damage to fetal neural cells and to the respiratory and cardiovascular system. The later potential health complications may, for example, have future effects on school attendance. TCZ policy may, therefore, have affected the long-term educational performance in the targeted locations, by providing better air quality early in life. It was indeed shown that its implementation is associated with a lower incidence of low weights at birth (Tanaka, 2015). A more direct and separate effect, protecting brain development and the cardiovascular-respiratory system, is also possible. Second, air pollution reductions, in China, were shown to increase productivity and labor supply of workers (Fan and Grainger, 2019; Chang et al., 2019; He et al., 2019), suggesting that parents may have been able to ensure higher incomes, following the TCZ policy. It has been shown that better nutrition and access to health care during pregnancy and early childhood is a simulating factor for long-term better cognitive abilities (Martorell, 2017; Currie, 2020). As family income is one of the main determinants of parental inputs, long-term human capital outcomes of the exposed children may further be affected, if early-childhood parental investments are altered as a consequence of the changes in their income.

The second channel concerns a direct income effect that is totally independent of changes in air quality. According to Hao et al. (2001), collieries producing more than 50 million tons of high-sulfur coal and a part of small power plants have been closed by the end of 1999. Decreases in employment by newly established foreign firms in TCZ locations had also been proven (Cai et al., 2016). The policy implementation may, therefore, have negatively affected labor market opportunities and earnings capacity of some parents, particularly those working in the power industry. If parental investments in children decreased as a consequence of this effect, long-term educational outcomes of the exposed children would have been negatively affected.¹⁴

Given the above potential channels, we present a simplified framework of how the TCZ policy may have affected the educational performance of early-life exposed children. An individual's educational performance, E , is a function of cognitive ability, A ,¹⁵ health

¹⁴In the case where the reduced earnings of parents is accompanied with a higher degree of stress and conflict at home, it may further reinforce the negative effects of the decrease in income, as exposure to high levels of cortisol in utero negatively affects children's cognition, health, and educational attainment later in life (Aizer et al., 2016).

¹⁵An extensive body of literature has shown that cognitive ability is strongly associated with a variety of educational outcomes including standardized test scores, school completion, post-secondary education

stock, h , individual characteristics, X , family characteristics, F and county characteristics, C : $E = e(A, h(I_1, I_2), X, F, C)$, where I_1 represents the inputs into the child's stock of health from early childhood, and I_2 is the inputs during the following years until the outcomes are observed.¹⁶ The cognitive ability also depends on inputs in early childhood, i_1 , and that in later life, i_2 , on the health stock and on other characteristics. Formally, $A = a(i_1, i_2, h(I_1, I_2), X, F, C)$. Hence, educational performance is given by

$$E = e(a(i_1, i_2, h(I_1, I_2), X, F, C), h(I_1, I_2), X, F, C) \quad (3.1)$$

Following the implementation of the TCZ policy, we assume that cohorts born in TCZ designated counties, right after the policy implementation, should have better quality inputs in terms of lower air pollution, and probably lower parental income, compared to those born just before the TCZ policy in the same counties. However, both cohorts would be exposed to the same environment at older ages. We can therefore assume that, following the implementation of the TCZ policy, there will be variations in I_j , by changes in air quality or in parental income, as shown above, (where $j=1, 2$ for cohorts born just after the TCZ policy in TCZ counties and $j=2$ for cohorts born just before the TCZ policy in TCZ counties). Comparing these two groups allows to detect the additional effect of changes to I_1 investments, following the TCZ policy, on educational performance at older ages:

$$\frac{\partial E}{\partial I_1} = \frac{\partial e}{\partial a} \frac{\partial a}{\partial h} \frac{\partial h}{\partial I_1} + \frac{\partial e}{\partial h} \frac{\partial h}{\partial I_1} \quad (3.2)$$

Using this reduced-form model, we can say that a variation in I_1 affects health stock, h , which itself would affect educational performance via two channels: either directly ($\frac{\partial e}{\partial h} \frac{\partial h}{\partial I_1}$) or indirectly through its effect on the cognitive ability ($\frac{\partial e}{\partial a} \frac{\partial a}{\partial h} \frac{\partial h}{\partial I_1}$).

In what follows, we try, first, to identify the overall effect of the TCZ environmental policy on future educational performance of exposed children during their early life ($\frac{\partial E}{\partial I_1}$). Then, we focus on the effect of the policy through its effect on pollution levels.

participation and other measures of student performance (Marks, 2013).

¹⁶Modeling the exact structure of these relationships is beyond the scope of this paper as they are much more complex and may involve other parts that are not presented here. Given the data availability, we focus on the reduced form relationship between early-childhood variation in inputs into health and cognitive ability and long-term educational performance.

3.4 Empirical framework

3.4.1 Long-term effects of exposure to the TCZ policy

The main goal of this study is to estimate the overall long-term effects of the exposure to an environmental regulation, the TCZ policy, in a very early stage of life (in utero and before age 1). We adopt a difference-in-differences (DID) approach, which estimates the effects, on long-term educational performance, for cohorts born into TCZ counties after the policy’s implementation, relative to counterfactual:

$$Y_{ict+15} = \beta_0 + \beta_1(TCZ_c \times Post_t) + \theta_1 X_i + \theta_2 Z_{ct} + \gamma_c + \kappa_{pt} + u_{ict} \quad (3.3)$$

where outcome Y_{ict+15} is a measure of educational performance, 15 years later, for individual i , born in county c in year t . In the context of our paper, using education measures instead of earnings to investigate the long-term effects of an environmental regulation presents several advantages. First, reported education is less likely to be subject of serious measurement errors than reported earnings, especially in rural areas where a high number of workers are self-employed. Second, contrary to using earnings, life cycle biases are less probable to bias estimations when using education measures, as education is generally completed early or mid-twenties (Black and Devereux, 2011). TCZ_c is an indicator variable equal to 1 if county c was designated as TCZ in 1998, and $Post_t$ is an indicator that equals 1 for the years after the TCZ was implemented.¹⁷ The interaction term equals 1 for TCZ counties after 1997. β_1 is the key parameter that estimates the DID long-term effect of the TCZ policy. X_i is a vector of time-varying individual characteristics, including each individual i ’s parental characteristics, that may affect the educational performance at older ages. Individual characteristics include gender, number of siblings, ethnicity indicator and urban *hukou* indicator. Parental characteristics include indicators for the mother’s and father’s levels of education (five separate indicators for each parent), the age of each parent at birth and continuous measures of both of the parents’ education. Z_{ct} is a vector of weather variables and county characteristics at the year of birth. Weather controls include a second-degree polynomial in precipitation and seven variables for 10-Fahrenheit degree temperature bins. Each 10-degree bin includes the number of

¹⁷Note that the non-TCZ designation does not mean that the locations are not affected by the environmental policy. It is more relevant to call TCZ localities as those where the policy is more stringent, compared to the non-TCZ localities. However, as we don’t have a measure of the intensity of exposure to TCZ policy, we use the discrete choice of being a TCZ locality or not. If TCZ policy was also responsible for reductions in air pollution in non-TCZ designated localities, especially in those located near TCZ localities, that would only understate our results.

days with the maximum temperature falling in the given 10-degree bin: 33-39, 40-49, 50-59, 60-69, 70-79, 80-89 and 90-99. Another variable that includes the number of days with the maximum temperature ≥ 100 is also added. We include precipitation and temperature variables since weather conditions may interfere with air pollution levels, with the rain washing away the air pollutants and temperature affecting their formation. While it was also well documented that rain and temperature early in life affect the later life outcomes (Maccini and Yang, 2009; Hu and Li, 2016). Finally, county characteristics at year of birth include a demographic variable (total population) and an economic variable (GDP per capita), used to control for their impact on both air pollution levels and long-term educational performance.¹⁸ γ_c are birth county fixed effects that absorb any time-invariant, unobserved determinants of educational performance for individuals born in a specific county. Finally, κ_{pt} are the province-by-year of birth fixed effects, which non-parametrically absorb any time-varying determinants of long-term educational performance for individuals born in a specific year and province. It helps purging, for example, any potential effects induced by policy changes at the province level. In all of our estimations, we cluster the standard errors at the county level to allow for county-specific correlated errors over time.

Early-childhood period is known as a critical and sensitive period of development. Moreover, the dynamic complementarities hypothesis suggests that earlier childhood investment in disadvantaged children is more effective for subsequent outcomes than later investments. Therefore, exposure to the beneficial effects of the environmental policy earlier in childhood may have had a higher positive effect than exposure later on. However, if sensitivity to air quality and to changes in parental income is higher at older ages, later childhood exposure to the environmental policy may be more or at least as effective as exposure at early childhood. This question is of clear policy relevance. Additional education or social measures may be needed for the age-group gaining less, in terms of educational performance, in order to reinforce the initial benefits of the environmental policy. Eq. (3.3) focuses on the long-term effects of exposure to the TCZ implementation between conception and age 1, and does not allow to test the variation in these effects across cohorts in age, at the time of the policy's implementation. To do so, we expand our sample to children born in years 1992-1999. All individuals born in 1999 in TCZ counties should have been exposed to the impacts of the TCZ policy implementation from conception onward. Those born in 1998 benefit from the TCZ policy in their year of birth, they may, thus, be partially exposed to its impacts in utero and fully exposed from birth

¹⁸County characteristics also allow to control for selection into fertility.

onward. Those born in years before 1998 experience the TCZ policy effects from age 1 or older depending on their year of birth. The interaction term in Eq. (3.3) is, therefore, replaced by all the possible interactions between birth year indicators and TCZ indicator, inducing the following distributed lag model:

$$Y_{ict+15} = \phi_0 + \sum_{k=1992}^{1999} \phi_k(TCZ_c \times 1(\text{year} = k)) + \theta_1 X_i + \theta_2 Z_{ct} + \gamma_c + \kappa_{pt} + \eta_{ict} \quad (3.4)$$

where $1(*)$ is an indicator variable that equals 1 if year is k . The coefficients of interest are the ϕ_k 's, and as not all of them are identified in the presence of county fixed effects, we normalize the coefficient for the 1997 cohort to be zero ($\phi_{1997} = 0$). The other ϕ_k 's coefficients measure, therefore, the effect of the TCZ policy on individuals who were age $(1998 - k)$ in 1998, in TCZ counties, with respect to those exposed to the policy's implementation at age 1.¹⁹ Control variables are those from model 3.3.

3.4.2 TCZ policy and changes in air quality

In the previous subsection, we looked at the overall net effects of early-life exposure to the TCZ environmental policy on long-term educational performance. Under the assumption that the TCZ designation is responsible for a variation in the county-level air pollution, Section 3.3 shows how the TCZ policy may have affected long-term outcomes through its effect on air quality.

Panel A of Figure 3.C.1 shows the trends in county-level annual means of SO₂ concentration of TCZ and non-TCZ counties from 1980 to 2000.²⁰ As expected, there is a notable difference between TCZ and non-TCZ counties in terms of the SO₂ concentration levels. They are higher in TCZ locations. We also notice that, before the TCZ policy implementation, the two groups of counties had had the same trend, showing increasing levels of the SO₂ concentrations until 1996, the year following the implementation of the 1995 APPCL. And, even though reductions in SO₂ concentrations started in 1997, those happening since the TCZ policy was put into effect, appear to be more important. SO₂ concentrations decreased for both groups of counties. However, the reduction in TCZ counties seems more maintained, especially between 1999 and 2000.²¹

In order to estimate the specific effect, that goes through the reductions in the SO₂ pollutant concentrations, of the TCZ policy, we build a two-step model. We first consider

¹⁹A negative age of exposure refers to exposure since conception.

²⁰Values of the SO₂ concentrations are to be taken with caution.

²¹Panel B of Figure 3.C.1 shows a new trend of rising SO₂ concentrations since 2003 and that may be due to China's Accession to the World Trade Organization during that year.

a difference-in-differences regression that allows to measure the effect of the TCZ policy on SO₂ concentration levels:

$$SO_{2ct} = \lambda_0 + \lambda_1(TCZ_c \times Post_t) + \alpha_1 X_i + \alpha_2 Z_{ct} + \gamma_c + \kappa_{pt} + \epsilon_{ict} \quad (3.5)$$

where SO_{2ct} is the annual mean of SO₂ concentration in county c and year t , measured in $\mu g/m^3$. TCZ_c and $Post_t$ indicators and other control variables are as defined in model 3.3. In the second step, we investigate the effect of the TCZ-induced changes in air quality, in children's county and year of birth, on their long-term outcomes, using the predicted concentrations of SO₂ from Eq. (3.5):

$$Y_{ict+15} = \delta_0 + \delta_1 S\hat{O}_{2ct} + \tau_1 X_i + \tau_2 Z_{ct} + \gamma_c + \kappa_{pt} + v_{ict} \quad (3.6)$$

Section 3.3 suggests that the TCZ policy may have affected children's outcomes in a way other than pollution reduction, by decreasing parental income. If this income effect was in place, then results of Eq. (3.6) will be downwardly biased.

3.5 Data and Descriptive Statistics

3.5.1 School outcomes

Our data on educational performance are retrieved from the fifth wave survey of the China Household Income Project of the year 2013 (hereafter CHIP13). It was conducted, in July and August of 2014, by the Annual Household Survey Office of Integration of Urban and Rural in National Bureau of Statistics, to collect data on the year 2013. It surveys rural and urban households from 15 provinces, 126 cities and 234 counties from east, center and west areas of China. It covers a variety of individual and household level social and economic information including income, assets, expenditure, employment, education and other demographic information. In this paper, we make use of both the urban and the rural surveys of CHIP13. Below we describe the measures of educational performance used in our analysis. This data is matched to other datasets based on the child's county of residence at the time of the survey.

Qualify for High School. Compulsory education in China includes a total of nine years of schooling in primary and junior middle schools, starting typically at the age of six. Additional education in high school is determined by the child's willingness to get more years of schooling. Children may self-select themselves into this additional education, so

that only students that think they can do well in high school will choose to continue their education. This category includes individuals that reported having more than 9 years of formal education. In the absence of this information, we use the reported educational level, including those who attended, or are attending at the end of 2013, a senior middle school, a vocational senior secondary school, a technical school, a specialized secondary school or in a higher level of education.

High School Entrance Exam Scores. High schools in China select students based on their high school entrance exam (HSEE) score, a standardized test at the province level and known as *zhongkao* in China. Students usually get tested in Chinese, Mathematics, English, Physics, Chemistry, Political Science and PE. Better quality high schools have higher threshold scores than lower quality high schools. While students opt for the best school among the ones they were accepted in, it is reasonable to assume that HSEE test scores correlate with high school quality. We follow Sun (2019) in proxying the HSEE scores by the quality of high school. The CHIP13 asked respondents to report the type of their high school if they ever studied in high school. Six types are proposed: (1) National or provincial level key middle school, (2) City or district level key middle school, (3) County level or other key middle school, (4) Non key middle school, (5) Specialized secondary school/ vocational senior secondary school/technical school, (6) Others. As more and better education resources are allocated to “key” and higher administrative level schools, compared to “non-key” and lower administrative level schools, we define the high quality high schools as those belonging to types (1), (2) and (3), assuming that children succeeding to attend these schools have better educational performance than their peers joining schools of types (4), (5) or (6).

Academic High School. Junior middle school graduates have the choice between joining an academic high school or a specialized/technical high school. Students wanting to attend an academic senior middle school must pass the high school entrance examination. Students also have the option to attend vocational and technical schools which provide a variety of training programs to produce all kinds of skillful workers. This educational path is opted for either by choice or because students failed the *zhongkao* exam. We define children as attending an academic high school if they have ever attended a high school of type (1), (2), (3) or (4).²²

²²For the High School Entrance Exam Scores and Academic High School variables, we drop those reporting a high school quality while at the same time reporting getting 9 or less years of education.

3.5.2 Air Pollution and TCZ Regulatory Status

We use SO₂ concentration data from the satellite-based Aerosol Optical Depth (AOD) retrievals provided by the National Aeronautics and Space Administration (NASA).²³ We particularly make use of the M2TMNXAER version 5.12.4 from the Modern-Era Retrospective Analysis for Research and Applications version 2 (MERRA-2). This product provides monthly AOD data since 1980 in grids of 0.5 degree (50 km) latitude*0.625 degree (60 km) longitude. We aggregate the SO₂ concentration data from grid to county level for each month, and then, average to annual level for each county.²⁴ This pollution dataset has been used in a number of previous studies (e.g., Chen et al., 2017b; Deschenes et al., 2020).

To identify whether each county in CHIP13 data was designated as TCZ in 1998, we rely on the “Official Reply to the State Council Concerning Acid Rain Control Areas and Sulfur Dioxide Pollution Control Areas” document.²⁵

3.5.3 Weather

Weather data are obtained from the Global Summary of the Year (GSOY) dataset, collected from the National Centers for Environmental Information (NCEI) under the National Oceanic and Atmospheric Administration (NOAA) of the United States. It includes temperature and precipitation measures for different weather stations across China, computed from the summary of the day observations of the Global Historical Climatology Network Daily dataset (GHCN-D). In addition to climate records, the latitude and longitude of each station’s location is provided. We rely on this location information to match each county represented in CHIP13 to the nearest weather station²⁶.

²³We cannot use ground-based pollution data as they are not available for years before 2000 at the county level. Chen et al. (2017b) found no statistical difference between the AOD data and the ground-based pollution data in China, conditional on geographic and year fixed effects.

²³https://goldsmr4.gesdisc.eosdis.nasa.gov/opendap/MERRA2_MONTHLY/M2TMNXAER.5.12.4/contents.html

²⁴Details on how pollution data are manipulated are described in Appendix 3.B.2.

²⁵More details on how TCZ status is affected to counties in CHIP13 are described in Appendix 3.B.1.

²⁶The number of weather stations changed over time, so in some cases, we linked more than one station to the same county.

3.5.4 County Characteristics

County level characteristics are available from EPS China Data.²⁷ These characteristics include county-year information on GDP per capita and total population.²⁸

3.5.5 Sample

For our main analysis, we restrict the sample to cohorts born in 1995-1999, the years immediately surrounding the policy implementation.²⁹ This results in a sample of 3363 rural (70%) and urban (30%) children, living in 216 different county. In order to match this data with other datasets at the county×year-of-birth level, the GB codes of counties were replaced by the county names (Ministry of civil affairs, 2014). An additional 5 observations were excluded from the sample, due to the lack of information on the county name corresponding to the GB code of these observations' counties, which reduces the sample to 3358 children, living in 214 different counties. Around 61% of these children live in a county that is designated as TCZ. About 32% of the sample is not matched to the county-level pollution data, the reason why we match them to the prefecture-level pollution data. Moreover, 9% of the sample is not matched to the corresponding county characteristics data. The final sample, used for each estimation, is different depending on the data availability for the considered outcome variable. About 36% of the sample have missing information about whether they joined high school, while about 56% have missing information about the quality of the high school. Considering all the missing values of the control variables, there are 1539 children in the remaining sample, for the outcome variable about the qualification for high school, and 1005 children, for the outcomes about the quality of high school attended.

To examine the air pollution channel, through which the TCZ policy implementation may affect long-term outcomes, we use only observations with available county level SO₂ concentrations. Moreover, our empirical strategy allows to include all observations with

²⁷County and City Data. Available at: <http://www.epschinadata.com/>.

²⁸See Appendix 3.B.3 for details about how county characteristics are manipulated.

²⁹Educational performance variables should be observed at age 15 for each child. Those born in 1999 are aged 15 in 2014, the year in which CHIP13 is conducted. The CHIP13 survey took place in July and August of 2014, while *zhongkao* exam is usually taken early June, and, in some cases, in late June or even early July. Therefore, some of those born in 1999 may be already in possession of their *zhongkao* results, at the time of the survey, while others are not. This induces the issue of whether the 1999 sample is sufficiently representative of the 1999 cohort. As the missing outcomes' data are due to age-related inability to participate in the measurement, because of the survey timing, and unrelated to the educational outcomes, missingness should not be a problem. Consequently, despite the smaller number of observations for the 1999 cohort, it is included in the analyses because it is more informative to use all available data that contribute to the estimation of the effects.

missing values for the outcome variables, when running the first step of the model (Eq. (3.5)). This results in 1760 observations collected from 91 different counties for the first step.

For the comparison of the long-term effects by age of exposure at the time of the TCZ implementation, we expand our sample to individuals born between 1992 and 1999. This leads to a sample of 5696 rural and urban children. 9 observations are additionally dropped for the lack of information on the county names corresponding to their GB codes, which results in a sample of 5687 children. Considering all the missing values of the control variables, there are 3189 children in the remaining sample, for the outcome variable about the qualification for high school, and 2073 children, for the outcomes about the quality of high school attended.

3.5.6 Descriptive statistics

Using the sample of individuals born between 1992 and 1997, Table 3.C.1 presents the coefficients on the TCZ indicator from separate regressions for each of the observable characteristics. As the TCZ status was not randomly assigned, it is expected to see differences between the two localities in the pre-TCZ period. Particularly, we found that TCZ counties tend to include children with a lower number of siblings, a higher mother and father education and higher probability of having the urban *hukou* compared to the rural one. There also seems to be differences in weather indicators between the two areas. TCZ counties have a higher average temperature and a higher total precipitation per year.

3.6 Empirical results

3.6.1 Exposure to TCZ policy in early childhood

Table 3.6.1 presents our difference-in-differences estimates of the TCZ implementation's effects on educational outcomes of those born in TCZ counties, 15 years later. The dependent variable in panel A is the likelihood of attending a high quality high school. Column (1) which controls for weather and county characteristics in addition to county and province by year of birth fixed effects, shows that those exposed to the TCZ policy implementation during conception and before age 1 are more likely to attend a higher quality high school, compared to counterfactual. More controls are added across the columns, addressing the concern that time varying individual characteristics that may explain the long-term outcomes are correlated with the TCZ status. Children's outcomes

Table 3.6.1: Effect of TCZ Implementation in the year of birth on long-term educational outcomes

	(1)	(2)	(3)	(4)
A. High quality high school				
TCZxPost	0.855** (0.349)	0.998*** (0.344)	0.998*** (0.356)	1.012*** (0.361)
Observations	939	939	939	939
Pseudo R ²	0.174	0.226	0.254	0.260
B. Academic high school				
TCZxPost	0.892** (0.435)	1.117** (0.488)	1.289** (0.523)	1.299** (0.531)
Observations	709	709	709	709
Pseudo R ²	0.184	0.229	0.282	0.282
C. Qualify for high school				
TCZxPost	-0.021 (0.371)	0.143 (0.411)	0.231 (0.414)	0.206 (0.417)
Observations	1126	1126	1126	1126
Pseudo R ²	0.126	0.204	0.229	0.257
Child characteristics	No	No	No	Yes
Parents characteristics1	No	Yes	Yes	Yes
Parents characteristics2	No	No	Yes	Yes
Weather controls	Yes	Yes	Yes	Yes
County characteristics	Yes	Yes	Yes	Yes
County fixed effects	Yes	Yes	Yes	Yes
ProvinceXyears fixed effects	Yes	Yes	Yes	Yes

Notes: This table reports regression coefficients from 12 separate pooled Probit regressions. Individual-level micro data is used for these regressions. The sample includes all observations for the years 1995-1999 and remains the same across all columns for each outcome. The outcome in panel A is a dummy variable that equals 1 if attending a high quality high school and 0 otherwise, the outcome in panel B is a dummy variable that equals 1 if attending an academic high school and 0 otherwise, and the outcome in panel C is a dummy variable that equals 1 if attending a high school and 0 otherwise. Estimates reported are that of the TCZxPost variable, which is an indicator that equals one for counties designated as TCZ interacted with an indicator that equals one for birth years after 1997. All regressions are unweighted and include controls for county characteristics (population, GDP per capita), weather variables (second-degree polynomials in annual precipitation, 10-degree bins based on daily maximum temperatures), province by year of birth fixed effects and county fixed effects. Additional controls are listed in the table and cover parents characteristics1 (continuous measures of both mother's and father's education, mother's age at birth), parents characteristics2 (father's age at birth, indicators for levels of education of both the mother and father) and individual characteristics (gender, ethnicity, number of siblings, urban hukou). Standard errors in parentheses are clustered at the county level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. See Table 3.C.2 for details about these estimations.

my differ by parents' education, for example, while systematic differences exist in the mother's and father's education between TCZ and non-TCZ counties (Table 3.C.1). We find that the exposure to the TCZ policy implementation, early in life, is associated with obtaining better exam results, and therefore, a higher predicted probability of joining a higher quality high school, in models including parents characteristics (columns (2) and (3)) and child characteristics (column (4)).³⁰

Panel B of Table 3.6.1 provides results using the likelihood of attending an academic high school with respect to attending a specialized/technical high school as the dependent variable. Estimates show that cohorts exposed to the TCZ implementation in utero and before age 1 are more likely to attend an academic high school. The effects are positive and significant across the different specifications adding more controls.

Finally, panel C estimates the effect on the probability of high school enrollment (likelihood of attending high school with respect to dropping out, either by choice or because of exam failure). The estimate is negative when we only control for weather and county characteristics, but becomes positive when we further control for parents and child characteristics. Differently from the previous outcomes, the coefficients fail to be statistically significant. In sum, our results suggest that the majority of the effect of the TCZ policy is occurring with respect to exam results and, therefore, the type of high school to attend instead of the qualification to enter high school.

The key identifying assumption for the validity of these results is that trends in outcomes between TCZ and non-TCZ counties would have evolved similarly in the absence of the policy, conditional on covariates. Table 3.C.3 presents, from Eq. (3.4), estimates of the interaction terms between TCZ indicator and children's year of birth dummies, compared to that of the 1997 year dummy, using high quality high school, academic high school and qualify for high school variables as dependent variables. These pairwise comparisons come in support for the identification assumption for Eq. (3.3): as the trends before the TCZ implementation between the treatment and control cohorts are almost similar for the three outcomes, we can suggest that the trends after 1998 would have been similar without the effects of the TCZ policy. We also notice that for children, born in TCZ counties during the two years after the TCZ policy implementation, there are some improvements in the cohorts' outcomes.³¹ These variations suggest additional benefits of exposure to the implementation of an environmental regulation between conception and

³⁰Each model is considered as independent of and incomparable to the other models in the different columns (see e.g., Buis, 2017).

³¹The 1999 cohort is represented by a smaller number of observations. Consequently, AMEs on that cohort may end up with large standard errors and wide confidence intervals. However, this loss of precision does not condemn the usefulness of the results.

age 1, compared with cohorts exposed to the same regulation at age 1 and later.

Table 3.C.4 provides additional evidence for the validity of our identification assumption. TCZ status is not randomly assigned. It is affected, in part, based on emission levels and concentrations of SO₂ pollutant in each location. Therefore, it is possible that the estimated TCZ effects are reflecting impacts of the factors that are conditioning air quality in the respective counties. In Table 3.C.4, we test for potential differences in trends of observable characteristics, following the TCZ policy implementation, between TCZ and non-TCZ counties. Each characteristic is used as the dependent variable in a separate regression, to compute the coefficient on the interaction term from Eq. (3.3). As we cannot test for the treatment status not covarying with unobservable characteristics, we assume that the absence of significant relations with observable characteristics implies an absence of significant correlations with unobservables (Altonji et al., 2005). Results suggest that trends, between TCZ and non-TCZ counties, in most of the observable characteristics, that may be determinants of the educational outcomes, are similar, further supporting our research design. There are two covariates that exhibit significant differences: number of siblings and precipitation. For this reason, we later replicate all regressions dropping the number of siblings variable to test for any changes in estimates. The small correlation with local economic trends, measured by the coefficient on GDP per capita, suggests little probability that economic shocks would bias our results. Other policies affecting educational outcomes, implemented around the time of the TCZ policy, may confound our results. The 9th Five-Year Plan decides on the different policies to implement for the years 1996-2000. We present, therefore, the balancing test results for the period 1996-1999 as a robustness check. The TCZ designation seems to balance the trends in important determinants of educational outcomes.

Incidental parameter problem.—In our basic specification, we estimate a fixed effects model where we include county and year of birth dummies to capture unobserved heterogeneity. However, considering the large number of per-county observations for some counties but the few observations for others, the fixed effects estimations may result in an incidental parameter problem (Neyman and Scott, 1948). To address this issue, we consider two alternative estimation approaches. First, we estimate the Correlated Random Effects model (CRE) for the three educational outcomes, by adding county-specific year averages of all time-varying covariates, rather than the county dummies, and the number of yearly data entries of each county (Wooldridge, 2019).³² The inclusion of the within-county means of all time-varying variables accounts for county time-invariant unobserved

³²Wooldridge (2019) developed the correlated random effects approach to be used for nonlinear models under unbalanced panels.

heterogeneity. This approach tries to approximate a “fixed effects” strategy without estimating many incidental parameters. Table 3.6.2 reports the results. The TCZ policy implementation is positively and statistically significantly associated with a higher probability to attend an academic high school, for those exposed between conception and age 1. The effect on the probability to attend a higher quality high school is positive but not precisely estimated. We reexamine the pre-existing trends using the CRE estimations of Eq. (3.4), for the three educational outcomes. Estimates of the interaction terms between each TCZ indicator and children’s year of birth dummy, compared to that of the 1997 year dummy, are presented in Table 3.C.5. Comparisons of each marginal effect, for years before 1998, with that of 1997 are close to zero and non significant, for the high quality high school outcome (except for the year 1992) and the academic high school outcome, but not for the qualification for high school variable.³³ These pairwise comparisons suggest that the trends for the two outcomes, high quality high school and academic high school, before the TCZ implementation, between the TCZ and non-TCZ cohorts, are almost similar, supporting the identification assumption of Eq. (3.3). The Table also shows that the estimates of the differences in AMEs, for those born in 1998-99, are positive and larger than zero, suggesting improvements in the outcomes of those born in TCZ counties, during the two years after the TCZ policy implementation.³⁴ To determine how large these effects are, we compute the DID estimates of the TCZ implementation effect, measured in probability of outcomes. Results are presented in Table 3.6.3. The average difference-in-differences in probability of attending a high quality high school is 12.5 percentage points, while it reaches 18.7 percentage points for the probability of attending an academic high school. This implies that our results are consistent with an important effect of exposure to the TCZ intervention between conception and age 1. Second, we present the Linear Probability Model (LPM) estimates, in Appendix (Table 3.C.6). Limitations of the LPM

³³These results suggest no differential effects of exposure to the TCZ policy starting at age 1, 2, 3, 4, 5 or 6, for the academic high school outcome. Moreover, even though we find no differential effects of exposure to the TCZ policy starting at age 1, 2, 3, 4 or 5, for the high quality high school outcome, we see an additional benefit for exposure at age 6, relative to exposure at age 1. We also see statistically significant additional beneficial effects of exposure at age 2, 3 and 6, relative to exposure at age 1, in terms of the probability to continue non-compulsory education. If, in fact, these differential effects are due to the TCZ policy, then, they may be explained by the decrease in the effectiveness of the policy, starting from year 2003, as shown in Figure 3.C.1. Those exposed, to the TCZ policy, at age 2, 3 or 6 benefit from more years of protection from air pollution, during school years, than those exposed at age 1. This suggests the need for the good implementation of the environmental policy throughout the childhood.

³⁴We also reexamine, using the Probit CRE, the potential differences in trends, following the TCZ policy, between TCZ and non-TCZ counties, for the three covariates estimated, in Table 3.C.4, by the pooled Probit with county dummies (Male, Han and Urban hukou). We find almost the same results as in Table 3.C.4, in terms of significance.

include getting some of the predicted probabilities outside of the unit interval. However, that does not necessarily compromise the usefulness of the estimates (Wooldridge, 2010). Moreover, to account for the violation of the homoskedasticity assumption, we report cluster-robust standard errors, adjusted at the county level. We find similar results in terms of significance and signs of the effects.³⁵ The TCZ policy implementation, during first year of birth, is associated with higher probabilities of attending a higher quality high school and an academic high school.^{36,37}

Table 3.6.2: Effect of TCZ Implementation in the year of birth on long-term cognitive outcomes, CRE

	(1)	(2)	(3)
	High quality high school	Academic high school	Qualify for high school
TCZxPost	0.473 (0.298)	1.002** (0.392)	0.192 (0.314)
Child characteristics	Yes	Yes	Yes
Parents characteristics1	Yes	Yes	Yes
Parents characteristics2	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes
County characteristics	Yes	Yes	Yes
ProvinceXyears fixed effects	Yes	Yes	Yes
Observations	997	959	1425
Pseudo R ²	0.183	0.234	0.237

Notes: This table reports regression coefficients from 3 separate CRE Probit regressions. All regressions include controls for county characteristics (population, GDP per capita) and their year means for each county, weather variables (second-degree polynomials in annual precipitation, 10-degree bins based on daily maximum temperatures) and their year means for each county. We also include the number of yearly data entries of each county. Additional controls are listed in the table and cover parents characteristics1 (continuous measures of both mother’s and father’s education, mother’s age at birth), parents characteristics2 (father’s age at birth, indicators for levels of education of both the mother and father) individual characteristics (gender, ethnicity, number of siblings, urban hukou), and province by year of birth fixed effects. Standard errors in parentheses are clustered at the county level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

³⁵We reexamine the pre-existing trends using the LPM estimations of Eq. (3.4). Figure 3.C.2 displaying estimates of the interaction terms between TCZ indicator and children’s year of birth dummies provides some evidence supporting the identification assumption for Eq. (3.3): the trends before the TCZ implementation between the TCZ and non-TCZ cohorts are almost similar for the two outcomes, high quality high school and academic high school, at the 90% confidence interval. Moreover, reexamining, the potential differences in trends, following the TCZ policy, between TCZ and non-TCZ counties, for the three covariates (Male, Han and Urban hukou) in Table 3.C.4, using the LPM, yields non-significant estimates, under the two samples (1992-1999 and 1996-1999).

³⁶The DID estimates of the TCZ implementation effect, measured in probability of outcomes, estimated by the LPM are higher than those computed with the CRE models.

³⁷It is also possible to overcome the incidental parameter problem using the analytical and jackknife bias corrections proposed by Fernández-Val and Weidner 2016. Their approach can be used in the case of both time and cross-sectional fixed effects, but weak dependence is imposed. Conditional maximum likelihood estimations can also be used, however, they impose conditional independence across time (Wooldridge, 2010).

Table 3.6.3: Impact of TCZ implementation in the year of birth on long-term educational outcomes: differences in probability (CRE)

	High quality high school	Academic high school	Qualify for high school
TCZ=0	0.425*** (0.055)	0.054 (0.152)	-0.370 (0.248)
Confidence Interval (95%)	[0.318, 0.532]	[-0.243, 0.352]	[-0.856, 0.116]
TCZ=1	0.551*** (0.055)	0.241** (0.117)	-0.302 (0.280)
Confidence Interval (95%)	[0.444, 0.658]	[0.012, 0.471]	[-0.851, 0.248]
TCZxPost	0.125*** (0.041)	0.187*** (0.064)	0.069 (0.085)
Confidence Interval (95%)	[0.045, 0.206]	[0.061, 0.313]	[-0.098, 0.236]
Observations	939	709	1126

Notes: This table reports the marginal effects (in probability metric) of Post in the TCZ (TCZ=1) and non-TCZ (TCZ=0) counties, following CRE Probit estimations of each outcome variable. Estimates for TCZxPost correspond to the pairwise comparisons of the average marginal effects. See notes to Table 3.6.2.

3.6.2 Mechanism: changes in air quality

The conditional mixed-process (CMP) technique, developed by Roodman (2011), is used to explore how the TCZ policy affected long-term educational outcomes, through its effect on air pollution.³⁸

Table 3.6.4 presents the results estimated by the CMP, using individual micro-data.³⁹ Although the data on SO₂ concentration are imperfect (albeit the best we can get, given the availability of this information), coefficients λ_1 from Eq. (3.5) (*First step*) are negative and significant, suggesting that the TCZ policy may have reduced the county-level annual mean SO₂ concentrations by 0.256-0.265 $\mu\text{g}/\text{m}^3$, relative to non-TCZ counties, in the post-TCZ period. The validity of these results relies on the assumption that trends in SO₂ concentrations between TCZ and non-TCZ counties are similar in the years prior to the TCZ policy implementation, conditional on covariates. Figure 3.C.3 suggests that the two groups of counties may have had similar trends in SO₂ concentrations before 1998, in the years closer to 1998 (Panel A).⁴⁰ The first set of coefficients, in Panel A of Table 3.6.4 (*Second step*), suggest that a 1 $\mu\text{g}/\text{m}^3$ decrease in the annual SO₂ concentration, in the year of birth, increases the predicted probabilities of attending an academic high school

³⁸The CMP technique allows to build a framework similar to that of the two-stage least squares, but while allowing for different sample sizes in each step of the estimations. We were, therefore, able to use a much larger dataset, covering more counties, in the first step (Eq. (3.5)), to estimate the relationship between the TCZ implementation and SO₂ concentration levels.

³⁹Note that estimations include only observations with available county level SO₂ concentrations.

⁴⁰Coefficients for years 1992 and 1993 are significantly negative, indicating that the difference in SO₂ concentrations, between TCZ and non-TCZ counties in our estimation sample, are smaller in years 1992 and 1993, compared to that of 1997.

and a higher quality high school. The estimated effects are significant at the conventional levels.

Incidental parameter problem.—Panel B of Table 3.6.4 reports results using the LPM to estimate the relationship between SO₂ concentrations and educational outcomes (*Second step*). Estimates are compatible with an increase in the probabilities of attending an academic high school and a higher quality high school, following a decrease in SO₂ concentrations. However, these effects are not precisely estimated.⁴¹

3.6.3 Treatment effect heterogeneity

Our main results show positive effects of exposure to the TCZ policy in one’s year of birth on children’s long-term outcomes, positively affecting their educational performance. However, this average effect may be hiding important differences in the effects of the TCZ policy across subgroups.

First, based on the son-preference rooted culture in China, males, for example, may already initially receive better protection from exposure to air pollution and probably a higher part of the parents’ monetary child investment. Biological arguments, however, suggest that female fetuses are less physiologically sensitive to environmental shocks than male fetuses (Tanaka, 2015). To examine whether girls benefit more from the TCZ policy, we estimate our model for the subsamples of boys and girls. The DID estimates, measured in probability of outcomes, are reported in Table 3.6.5. Panel A highlights that boys are statistically significantly more likely to get additional beneficial effects from being exposed to the TCZ policy between conception and age 1, in terms of having higher exam results, thus, attending better quality high schools. Moreover, even though, both girls and boys, exposed to the TCZ policy implementation, early in life, are more likely to choose an academic high school rather than a specialized/technical one, most of the increase in this probability relates to the girls. This indicates that environmental policies may contribute to reducing the gender gap in education.

We further examine heterogeneity in the treatment effect by the parents’ education. First, the beneficial effects may be concentrated among low-educated parents’ children. A higher parental education may reflect a higher knowledge and a higher socioeconomic status, allowing better protection ex-ante and ex-post against exposure of children to air

⁴¹It is also possible to extend the CRE approach to produce the predicted SO₂ concentrations following the TCZ implementation, by relying on the two-stage control function approach, as suggested by Papke and Wooldridge (2008) and Lin and Wooldridge (2019). We don’t present this approach as it was not possible, in our case, to produce bootstrapped standard errors, to correct for adding the first-step residuals in the second stage.

Table 3.6.4: Effect of TCZ Implementation in the year of birth on long-term cognitive outcomes: effects through changes in air quality

	(1)	(2)	(3)
	High quality high school	Academic high school	Qualify for high school
<i>Panel A. FE Probit</i>			
<i>Second step</i>			
SO ₂ concentration	-2.765** (1.159)	-2.955*** (0.373)	-0.765 (1.764)
Observations	648	499	844
<i>First step</i>			
TCZxPost	-0.265* (0.135)	-0.256** (0.129)	-0.256** (0.128)
Observations	1760	1760	1760
<i>Panel B. LPM</i>			
<i>Second step</i>			
SO ₂ concentration	-1.434 (0.874)	-0.385 (0.503)	-0.148 (0.317)
Observations	685	685	1109
<i>First step</i>			
TCZxPost	-0.256** (0.128)	-0.256** (0.128)	-0.256** (0.128)
Observations	1760	1760	1760
Child characteristics	Yes	Yes	Yes
Parents characteristics1	Yes	Yes	Yes
Parents characteristics2	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes
County characteristics	Yes	Yes	Yes
County fixed effects	Yes	Yes	Yes
ProvinceXyears fixed effects	Yes	Yes	Yes

Notes: This table reports coefficients from 6 separate regressions. Each regression estimates, in *Second step*, the effects of exposure, in the year of birth, to SO₂ concentrations, predicted using *First step*. SO₂ concentration is measured by the annual means. Regressions are performed using the CMP strategy where two different sample sizes are used for the estimations of Eq. (3.5) (*First step*) and Eq. (3.6) (*Second step*). Panel A reports results of Eq. (3.6) based on the fixed effects Probit while Panel B. reports results of Eq. (3.6) from the LPM. See notes to Table 3.6.1.

pollution. However, low-educated mothers may be more likely to work in the outside, being more exposed to air pollution during pregnancies, while fetuses of lower educated parents may already suffer lower initial health endowments, making them more vulnerable to air pollution. Second, effects may be lower for low-educated parents' children, if these parents learned to avoid outdoor pollution during pregnancies and in the early life of children, thanks to their long-term exposure to air pollution. A second reason for a lower effect, for these children, is the negative impact of the TCZ policy on their parents' incomes (as explained in Section 3.3). Moreover, Becker et al. (2018) show that wealthy parents invest, on average, more in their children than poorer ones. Therefore, if, by the potentially dynamic complementarities in human capital accumulation, early benefits of the TCZ policy are reinforced by later investments, then children of wealthier parents will benefit more from the TCZ policy than children of poorer parents. In panels B and C of Table 3.6.5, we report results from sub-samples divided by the father's and the mother's education attainments, respectively. We find that benefits associated with the TCZ policy significantly relate to children of low educated fathers, in terms of better exam results and, therefore, attending a higher quality high school. While, exposed children of high educated mother or father are more likely to get into an academic high school, instead of a specialized/technical one. In terms of magnitude, the benefits are larger for the relatively disadvantaged children, suggesting that the TCZ policy may have helped reducing educational disparities between the two groups of children. LPM results, presented in Table 3.C.7, support our previous estimates. Exposure of boys and children of low educated fathers to the TCZ policy, during their first year of birth, is associated with a higher probability to attend a higher quality high school.

3.6.4 Projected higher education and wage effects

Given the available data, it is still early to directly assess the long-term higher education and labor market effects of the TCZ environmental regulation. However, educational performance may be an important driver of these outcomes. A broad literature in economics shows that educational achievements are strong determinants of employment and earnings later in life (Chetty et al., 2011; Currie et al., 2012). It is plausible therefore, to think that improvements in education outcomes translate into better overall economic status, later in life. Hence, we evaluate the relationship between the measures of educational performance we employed in our analysis and later outcomes, using older cohorts from the same survey. To do so, we consider those born in 1990-94 (aged 19-23 when outcomes are observed) to estimate the effects of educational performance on higher education out-

Table 3.6.5: Heterogeneity in the TCZ effects across Subpopulations: differences in probability (CRE)

	(1)	(2)	(3)
	High quality high school	Academic high school	Qualify for high school
<i>Panel A. Boys and girls</i>			
Boys	0.195*** (0.048)	0.118*** (0.045)	0.190 (0.153)
Observations	502	459	733
Girls	-0.057 (0.173)	0.430** (0.218)	-0.096* (0.058)
Observations	452	416	478
<i>Panel B. High and low education of father</i>			
High father's education	0.075 (0.064)	0.233*** (0.034)	-0.044 (0.069)
Observations	536	486	581
Low father's education	0.437** (0.195)	0.050 (0.196)	0.041 (0.109)
Observations	429	386	727
<i>Panel C. High and low education of mother</i>			
High mother's education	0.096 (0.063)	0.206** (0.088)	-0.190 (0.154)
Observations	488	420	405
Low mother's education	0.144 (0.203)	-0.086 (0.212)	0.079 (0.126)
Observations	480	459	819
Child characteristics	Yes	Yes	Yes
Parents characteristics1	Yes	Yes	Yes
Parents characteristics2	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes
County characteristics	Yes	Yes	Yes
ProvinceXyears fixed effects	Yes	Yes	Yes

Notes: Each entry reports the difference between the marginal effects (in probability metric) in the TCZ and non-TCZ counties (following the CRE estimation for the considered subsample). High (low) father's and mother's education is defined as having a number of years of schooling that is above or equal (below) 9. See notes to Table 3.6.2.

comes, while we study those born in 1979-85 (aged 28-34 when outcomes are observed) to get the effects on earnings. We focus on the following outcome variables:

National College Entrance Exam score. Every year, and in order to join a higher education institution in China, high school 12th grade students must take the National College Entrance Exam (NCEE, or gaokao). It is considered as a high stakes exam as it is the one and only determinant for post-secondary education admission. Students are to choose one of two important tracks in their first year of high school, the arts track or the science track. The NCEE exam papers differ depending on the chosen track; however, mathematics, English and Chinese are three compulsory exams for both tracks. The full score for the NCEE is set at 750 points. Respondents of CHIP13 were asked to report their NCEE scores.

Higher education institutions participation. Post-secondary education institutions select students depending on their NCEE score being higher than a threshold set by these institutions.

Earnings. This is about the logarithm of the annual total income (total wage income which may include various monetary subsidies or net business income) in 2013 in Yuan. When the income is earned by more than one person, survey participants divide the total sum by person.

Table 3.6.6 shows that attending a high quality high school is associated with an increase of about 50 points in the NCEE score, an increase in the probability of having a NCEE score above the 75%-tile of the score distribution, and an increase in the probability of attending college/university. Controlling for individual and parental characteristics, the estimated coefficients on the NCEE scores become slightly lower but are still statistically significant at the 1% level. Given our results on the positive association between the TCZ policy and the probability to attend a higher quality high school, TCZ policy exposure, in early childhood, may have also positively affected higher education outcomes. Table 3.6.7 also reveals positive significant relationships between both being in an academic high school and being in a high quality high school and future earnings. Additional controls are added in each column. We also control for the years of education in columns (3)-(5), as the high quality high school and the academic high school variables may be affecting earnings through their effect on education level. However, the coefficients on these two variables remain positive and significant, suggesting a direct effect as well. Attending a high quality high school increases the future earnings by about 29.43% (Column 5), while attending an academic high school, rather than a technical/specialized one, increases future earnings by about 18.77% (Column 5). These results suggest that the TCZ policy exposure, in

early childhood, may have also positively affected earnings.

3.7 Robustness checks

In this section, we further explore the robustness of our results.

Selective migration.—First, we examine whether the perceived improvements in air quality and changes in the labor market opportunities due to the TCZ implementation changed the characteristics of the population in TCZ counties, resulting also in changes in the characteristics of the children born in there. If that was the case, part of the positive effects on the long-run cognitive outcomes we are getting may be driven by these changes in characteristics, instead of a causal impact from the early-life exposure to the TCZ policy. We show that this may not be the case. First, unlike most of other countries, permanent internal migration is particularly a complicated process in China. The *hukou* system relates each Chinese citizen to its place of birth and restricts the change of the registered residence only for those meeting certain requirements, e.g., having good education, getting a stable job or owning a permanent house in the destination. Therefore, there are two types of internal migrants in China. Those migrating without changing their *hukou*, they constitute the majority of internal migration in China and are known as the floating population, migrating usually repeatedly over short periods of time. The second type is those who migrate permanently, succeeding to change their *hukou*.⁴² Those migrating temporarily are more likely to leave their family behind in their place of origin. This is even more likely when health care is needed, such as in the case of pregnancy, since access to health services is related to one's *hukou* place of residence.

The smaller part of migrants that are able to move their *hukou* to their place of destination may probably move to counties that are expected to have cleaner air due to the TCZ policy. If this is really happening and as this type of migrants are also expected to have a higher socioeconomic status, our estimates may be biased.⁴³ However, in Table

⁴²In our CHIP13 urban survey, only 3.78% of the surveyed individuals (and only 0.11% of those born between 1995-1999) had their current *hukou* out of the district/county in which they are being surveyed, suggesting a low proportion of migrants living in a county/ district different from that mentioned in their *hukou*. On the other hand, only 10.96% of the respondents (and only 0.68% of those born between 1995-1999) reported that they had changed their *hukou* from rural/urban *hukou* to resident *hukou*. 26.66% (and only 0.83% of those born between 1995-1999) reported changing their *hukou* from rural to urban. In the CHIP13 rural survey, these proportions are even lower. Only 1.01% of the surveyed individuals (and only 0.02% of those born between 1995-1999) had their current *hukou* out of the district/county in which they are being surveyed. Only 9.86% of the respondents (and only 0.54% of those born between 1995-1999) reported that they had changed their *hukou* from rural/urban *hukou* to resident *hukou* while 23.99% (and only 1.07% of those born between 1995-1999) reported changing their *hukou* from rural to urban.

⁴³Chen et al. (2017b) showed that migration at the county level may react to changes in air pollution,

Table 3.6.6: Effect of school quality on higher education outcomes, 1990-1994 birth cohorts

	(1)	(2)	(3)
A. NCEE score			
High quality high school	51.424*** (4.798)	48.049*** (4.896)	46.314*** (4.927)
Observations	1457	1457	1457
R ²	0.073	0.404	0.411
B. NCEE score > 75%-tile			
High quality high school	0.667*** (0.084)	0.828*** (0.104)	0.805*** (0.105)
Observations	1186	1186	1186
R ²	0.046	0.169	0.174
C. NCEE score < 25%-tile			
High quality high school	-0.490*** (0.083)	-0.707*** (0.106)	-0.683*** (0.108)
Observations	1039	1039	1039
R ²	0.028	0.184	0.188
D. Went college			
High quality high school	0.675*** (0.115)	0.854*** (0.157)	0.820*** (0.162)
Observations	654	654	654
R ²	0.054	0.244	0.265
Individual characteristics	No	Yes	Yes
Parents characteristics	No	No	Yes
County fixed effects	No	Yes	Yes
Province fixed effects	No	Yes	Yes
Test year fixed effects	No	Yes	Yes

Notes: This table reports regression coefficients from 12 separate regressions. The sample includes all individuals born in 1990-1994 and remains the same across all columns for each outcome. Additional controls are added in each column and include individual characteristics (gender, ethnicity, urban/rural survey indicator), parents characteristics (continuous measure of both mother's and father's education, mother's and father's age at birth), in addition to county, province and year of NCEE test fixed effects. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3.6.7: Returns to education, 1979-1985 birth cohorts

	(1)	(2)	(3)	(4)	(5)
Panel A.					
High quality high school	0.213*** (0.056)	0.348*** (0.064)	0.269*** (0.067)	0.272*** (0.068)	0.258*** (0.067)
years of education			0.049*** (0.014)	0.050*** (0.015)	0.049*** (0.015)
Observations	701	701	701	701	701
R ²	0.020	0.397	0.410	0.413	0.430
Panel B.					
Academic high school	0.199*** (0.057)	0.257*** (0.065)	0.181*** (0.067)	0.182*** (0.067)	0.172*** (0.066)
years of education			0.058*** (0.014)	0.058*** (0.015)	0.055*** (0.015)
Observations	701	701	701	701	701
R ²	0.017	0.381	0.401	0.403	0.421
Individual characteristics	No	Yes	Yes	Yes	Yes
Parents characteristics	No	No	No	Yes	Yes
Job characteristics	No	No	No	No	Yes
County fixed effects	No	Yes	Yes	Yes	Yes
Province fixed effects	No	Yes	Yes	Yes	Yes

Notes: This table reports regression coefficients from 10 separate regressions. The sample includes all individuals born in 1979-1985 and remains the same across all columns. The outcome variable is the log annual earnings in 2013. Additional controls are added in each column and include individual characteristics (gender, ethnicity, urban/rural survey indicator, age and age square in 2013), parents characteristics (continuous measure of both mother's and father's education, mother's and father's age at birth), job characteristics (self-employment indicator, industry, occupation), in addition to county and province fixed effects. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

3.C.4 we show that the TCZ implementation did not induce differential changes neither in parental education nor in GDP per capita, in the years after TCZ designation, in the newly regulated counties. These results suggest little evidence for a bias in our estimates due to differential sorting based on observable characteristics.

County of residence versus county of birth.—Another concern in our analysis is that we are only observing the county in which the child is living at the time of the survey. If the current county of residence is different from the county in which they were born, this may constitute a potential source of measurement error for the treatment variable. However, as mentioned above, permanent migration as a household is less likely to happen in China. Moreover, children’s migration before age 16 is even less likely since their access to education is also related to their *hukou* of birth.

Differences in trends.—In Table 3.C.4, we found that the TCZ policy implementation is associated with a lower number of siblings for children living in counties designated as TCZ. TCZ counties already exhibited a lower number of siblings in the pre-TCZ period (Table 3.C.1). However, if parents in TCZ counties opted for an even lower number of children following the TCZ policy, this finding may bias our results if the number of siblings significantly affects the educational performance of each child. Moreover, in the specification using only the 1996-1999 cohorts, we see that the TCZ policy implementation is associated with a higher number of males. If parents opted for a lower number of children and, because of the son-preference culture, it resulted in selective pregnancies with only males, then our results may be biased if gender significantly affects the educational outcomes. For this reason, we replicate our main results without introducing the number of siblings and/or the indicator for gender as covariates. Results (for fixed effects models, CRE models and LPM) remain the same in terms of sign and significance.⁴⁴

Alternative clustering.—Our main results are clustered at the county level, to account for the fact that the variation we use to estimate the effects of the TCZ policy is at the county-level. In this robustness check, we cluster the standard errors at a higher administrative level, the province level, to account for both autocorrelation and spatial correlation across counties within each province.⁴⁵ We find that accounting for dependence within provincial level increases our standard errors a bit more but the significance levels of the results are the same, using the fixed effects and CRE models (the DID estimate for the academic high school variable is no longer significant, using the LPM, due to the

and that well educated people at the beginning of their professional careers are driving this migration. However, this is not evidence of permanent migration nor of the family migrating together to the destination.

⁴⁴Tables are omitted for simplicity but are available upon request.

⁴⁵Note that each province can include counties with different TCZ designation: TCZ or non-TCZ.

much higher standard errors).⁴⁶

Urban versus rural.— In our baseline results, we use data from both the urban and rural CHIP13 household surveys. If urban areas are more likely to be designated as TCZ than rural areas, then a concern is that our results are being driven by simple comparisons between rural and urban administrative divisions. To ensure that this is not the case, we restrict our analysis to using only the rural sample. Estimates, in Table 3.C.8, show slightly lower significance levels, compared to the main results, which can be explained by the higher standard errors, which may itself be due to the lower sample sizes. However, DID effects, for the probability to attend a higher quality high school (Panel B) or an academic high school (Panel A), remain significant, at the 10% level, suggesting that the effect we found is not produced by comparisons between urban and rural children.

Alternative research design.—The results presented until now in this paper are based on a difference-in-differences design that uses the overall available sample while controlling for different characteristics. However, a concern about a bias in our estimates may still arise if omitted heterogeneity that is related to the TCZ designation is driving the apparent difference in our outcomes between those born in TCZ counties and those born in non-TCZ counties, rather than the real effect of the treatment. To further test the robustness of our results, we use the propensity score matching method to restrict our sample to TCZ and non-TCZ counties that have similar characteristics. We use both mother’s and father’s years of education, weather variables and county characteristics variables as covariates to compute propensity scores of being designated as TCZ.⁴⁷ In a second step, we investigate the long-term effects of TCZ implementation on children’s educational performance using only the matched sample. Table 3.C.9 reports results from our DID estimation of the TCZ effects using the matched sample. Estimates remain the same across the specifications, in terms of sign and significance, increasing the confidence in our empirical strategy. The DID estimates of the TCZ implementation effect, measured in probability of outcomes, are presented for the CRE model. They vary little compared to the main results. The average difference-in-differences in probability of attending a high quality high school is 14.3 percentage points, while it reaches 16.5 percentage points for the probability of attending an academic high school.⁴⁸

Overall, all estimates remain similar across the different robustness checks, suggesting that the main results are not driven by inappropriate identification assumptions.

⁴⁶Tables are omitted for simplicity but are available upon request.

⁴⁷The logistic regression with the nearest-neighbor matching within the caliper (1:1 pairing) is used to construct the propensity scores.

⁴⁸Note that Stata does not account for the fact that propensity scores used for the matching procedure are estimated not the real ones.

3.8 Conclusion

In this paper, we provide the first empirical evidence, in the context of a developing country, of the additional benefits of exposure to an environmental policy between conception and age 1, in terms of educational performance. Using the difference-in-differences approach, we compare cohorts born in TCZ counties, subjected to particularly stringent directives, just before and after the TCZ implementation, to the same difference among cohorts born in non-TCZ counties. Our estimated reduced form effects capture the full environmental policy impact, including any changes in air pollution levels and changes in the labor market outcomes and opportunities for parents.

Considering the cohorts in our sample counties, the results are consistent with an important relationship between environmental regulation exposure, in utero and before age 1, and educational performance, 15 years later. Particularly, we found that the exposed children have higher predicted probabilities to attend a better quality high school, which can be explained by a higher ability to obtain better scores in a standardized high school entrance exam. They were also found to be more likely to join an academic, rather than a specialized/technical high school which focuses on manual labor training. Projecting forward, we showed that our educational performance measures may impact later educational attainment and earnings, suggesting even more benefits of the environmental policy. In a further step, we present suggestive evidence that the TCZ policy effects act through improvements in SO_2 concentrations, even though other channels are possible. Moreover, we found that the beneficial effects of exposure to the environmental policy, since conception and before age 1, are reinforced among cohorts born to fathers with low levels of education and among girls. These results suggest that environmental policies enhance educational performance while playing a role in reducing educational gaps. We also found results suggesting no differential benefits, in terms of higher predicted probabilities to attend a higher quality high school and an academic high school, from exposure to the TCZ implementation starting at age 1, 2, 3, 4 or 5. However, that does not imply the absence of positive effects. In case of beneficial effects at these slightly older ages, this suggests that the benefits of exposure to the TCZ policy are larger than the ones examined in this paper, including a wider age-group during early-life.

Even though our analysis presents the caveat of being limited by multiple data restrictions, our attempt to examine the importance of environmental policies for human capital formation suggests positive and significant associations. Future research is, however, needed to further examine the long-term effects of the TCZ policy on educational

and economic outcomes, using larger and more recent databases.

Bibliography

- Aizer, A., Stroud, L., and Buka, S. (2016). Maternal stress and child outcomes: Evidence from siblings. *Journal of Human Resources*, 51(3):523–555.
- Almond, D., Currie, J., and Duque, V. (2018). Childhood circumstances and adult outcomes: Act ii. *Journal of Economic Literature*, 56(4):1360–1446.
- Almond, D., Edlund, L., Li, H., and Zhang, J. (2010). Long-term effects of early-life development: Evidence from the 1959 to 1961 china famine. In *The economic consequences of demographic change in East Asia*, pages 321–345. University of Chicago Press.
- Altonji, J. G., Elder, T. E., and Taber, C. R. (2005). Selection on observed and unobserved variables: Assessing the effectiveness of catholic schools. *Journal of political economy*, 113(1):151–184.
- Angang, H., Linlin, H., and Zhixiao, C. (2005). China’s economic growth and poverty reduction (1978–2002). In *India’s and China’s Recent Experience with Reform and Growth*, pages 59–90. Springer.
- Becker, G. S., Kominers, S. D., Murphy, K. M., and Spenkuch, J. L. (2018). A theory of intergenerational mobility. *Journal of Political Economy*, 126(S1):S7–S25.
- Bharadwaj, P., Gibson, M., Zivin, J. G., and Neilson, C. (2017). Gray matters: Fetal pollution exposure and human capital formation. *Journal of the Association of Environmental and Resource Economists*, 4(2):505–542.
- Black, S. and Devereux, P. (2011). Recent developments in intergenerational mobility, handbook of labor economics, amsterdam, north-holland.
- Black, S. E., Devereux, P. J., and Salvanes, K. G. (2007). From the cradle to the labor market? the effect of birth weight on adult outcomes. *The Quarterly Journal of Economics*, 122(1):409–439.
- Brockmeyer, S. and d’Angiulli, A. (2016). How air pollution alters brain development: the role of neuroinflammation. *Translational neuroscience*, 7(1):24–30.
- Buis, M. L. (2017). Logistic regression: When can we do what we think we can do. *Unpublished note*, 2.
- Cai, X., Lu, Y., Wu, M., and Yu, L. (2016). Does environmental regulation drive away inbound foreign direct investment? evidence from a quasi-natural experiment in china. *Journal of Development Economics*, 123:73–85.
- Chang, T. Y., Graff Zivin, J., Gross, T., and Neidell, M. (2019). The effect of pollution on worker productivity: evidence from call center workers in china. *American Economic Journal: Applied Economics*, 11(1):151–72.

- Chaudry, A., Wimer, C., Macartney, S., Frohlich, L., Campbell, C., Swenson, K., Oelrich, D., and Hauan, S. (2016). Poverty in the united states: 50-year trends and safety net impacts. *Office of the Assistant Secretary for Planning and Evaluation*.
- Chen, R., Yin, P., Meng, X., Liu, C., Wang, L., Xu, X., Ross, J. A., Tse, L. A., Zhao, Z., Kan, H., et al. (2017a). Fine particulate air pollution and daily mortality. a nationwide analysis in 272 chinese cities. *American journal of respiratory and critical care medicine*, 196(1):73–81.
- Chen, S., Oliva, P., and Zhang, P. (2017b). The effect of air pollution on migration: evidence from china. Technical report, National Bureau of Economic Research.
- Chen, X., Zhang, X., and Zhang, X. (2017c). Smog in our brains: Gender differences in the impact of exposure to air pollution on cognitive performance.
- Chetty, R., Friedman, J. N., Hilger, N., Saez, E., Schanzenbach, D. W., and Yagan, D. (2011). How does your kindergarten classroom affect your earnings? evidence from project star. *The Quarterly journal of economics*, 126(4):1593–1660.
- Cunha, F. and Heckman, J. (2007). The technology of skill formation. *American Economic Review*, 97(2):31–47.
- Cunha, F. and Heckman, J. J. (2008). Formulating, identifying and estimating the technology of cognitive and noncognitive skill formation. *Journal of human resources*, 43(4):738–782.
- Currie, J. (2020). Child health as human capital. *Health economics*, 29(4):452–463.
- Currie, J., Thomas, D., et al. (2012). Early test scores, school quality and ses: Longrun effects on wage and employment outcomes. *35th Anniversary Retrospective*, 35:185–214.
- Dejmek, J., Selevan, S. G., Benes, I., Solanský, I., and Srám, R. J. (1999). Fetal growth and maternal exposure to particulate matter during pregnancy. *Environmental health perspectives*, 107(6):475–480.
- Deng, Q., Lu, C., Norbäck, D., Bornehag, C.-G., Zhang, Y., Liu, W., Yuan, H., and Sundell, J. (2015). Early life exposure to ambient air pollution and childhood asthma in china. *Environmental research*, 143:83–92.
- Deschenes, O., Wang, H., Wang, S., and Zhang, P. (2020). The effect of air pollution on body weight and obesity: Evidence from china. *Journal of Development Economics*, 145:102461.
- Fan, M. and Grainger, C. (2019). The impact of air pollution on labor supply in china. Technical report, Working Paper.
- Fernández-Val, I. and Weidner, M. (2016). Individual and time effects in nonlinear panel models with large n, t. *Journal of Econometrics*, 192(1):291–312.
- Guo, Y., Chen, Q., Zhai, S., and Pei, C. (2020). Does private tutoring improve student learning in china? evidence from the china education panel survey. *Asia & the Pacific Policy Studies*, 7(3):322–343.
- Hack, M., Breslau, N., Aram, D., Weissman, B., Klein, N., and Borawski-Clark, E. (1992). The effect of very low birth weight and social risk on neurocognitive abilities at school age. *Journal of Developmental and Behavioral Pediatrics*.
- Hao, J., He, K., Duan, L., Li, J., and Wang, L. (2007). Air pollution and its control in china. *Frontiers of Environmental Science & Engineering in China*, 1(2):129–142.

- Hao, J., Wang, S., Liu, B., and He, K. (2001). Plotting of acid rain and sulfur dioxide pollution control zones and integrated control planning in china. *Water, Air, and Soil Pollution*, 130(1-4):259–264.
- He, J., Liu, H., and Salvo, A. (2019). Severe air pollution and labor productivity: Evidence from industrial towns in china. *American Economic Journal: Applied Economics*, 11(1):173–201.
- He, K., Huo, H., and Zhang, Q. (2002). Urban air pollution in china: current status, characteristics, and progress. *Annual review of energy and the environment*, 27(1):397–431.
- Heckman, J. J., Lochner, L. J., and Todd, P. E. (2006). Earnings functions, rates of return and treatment effects: The mincer equation and beyond. *Handbook of the Economics of Education*, 1:307–458.
- Hering, L. and Poncet, S. (2014). Environmental policy and exports: Evidence from chinese cities. *Journal of Environmental Economics and Management*, 68(2):296–318.
- Hijmans, R. and University of California, Berkeley, Museum of Vertebrate Zoology (2015). Third-level administrative divisions, china, 2015. UC Berkeley, Museum of Vertebrate Zoology. Available at: <http://purl.stanford.edu/xg824mz9880>.
- Hu, Z. and Li, T. (2016). Too hot to hold: the effects of high temperatures during pregnancy on birth weight and adult welfare outcomes.
- Isen, A., Rossin-Slater, M., and Walker, W. R. (2017). Every breath you take—every dollar you’ll make: The long-term consequences of the clean air act of 1970. *Journal of Political Economy*, 125(3):848–902.
- Li, W. and Zhang, K. (2019). Does air pollution crowd out foreign direct investment inflows? evidence from a quasi-natural experiment in china. *Environmental and Resource Economics*, 73(4):1387–1414.
- Lin, W. and Wooldridge, J. M. (2019). Testing and correcting for endogeneity in nonlinear unobserved effects models. In *Panel data econometrics*, pages 21–43. Elsevier.
- Liu, Y., Xu, J., Chen, D., Sun, P., and Ma, X. (2019). The association between air pollution and preterm birth and low birth weight in guangdong, china. *BMC Public Health*, 19(1):1–10.
- Maccini, S. and Yang, D. (2009). Under the weather: Health, schooling, and economic consequences of early-life rainfall. *American Economic Review*, 99(3):1006–26.
- Marks, G. N. (2013). *Education, social background and cognitive ability: The decline of the social*. Routledge.
- Martorell, R. (2017). Improved nutrition in the first 1000 days and adult human capital and health. *American Journal of Human Biology*, 29(2):e22952.
- McCormick, M. C., Workman-Daniels, K., and Brooks-Gunn, J. (1996). The behavioral and emotional well-being of school-age children with different birth weights. *Pediatrics*, 97(1):18–25.
- Ministry of civil affairs (2014). Administrative division codes of the people’s republic of china at county level and above in 2013 (as of december 31, 2013). Available at: <http://www.mca.gov.cn/article/sj/xzqh/1980/201507/20150715854922.shtml>.

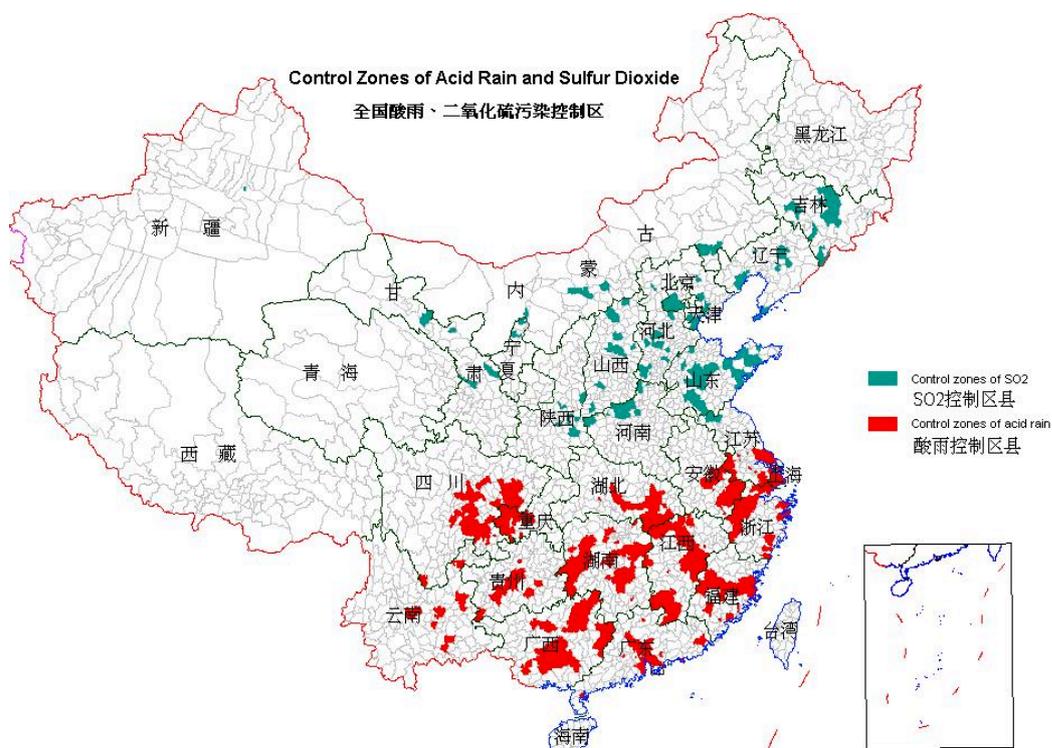
- Molina, T. (2021). Pollution, ability, and gender-specific investment responses to shocks. *Journal of the European Economic Association*, 19(1):580–619.
- NBS of China (2019). China statistical yearbook. Available at: <http://www.stats.gov.cn/tjsj/ndsj/2019/indexeh.htm>.
- Neyman, J. and Scott, E. L. (1948). Consistent estimates based on partially consistent observations. *Econometrica: Journal of the Econometric Society*, pages 1–32.
- Nilsson, J. P. (2009). The long-term effects of early childhood lead exposure: Evidence from the phase-out of leaded gasoline. *Institute for Labour Market Policy Evaluation (IFAU) Work. Pap.*
- Papke, L. E. and Wooldridge, J. M. (2008). Panel data methods for fractional response variables with an application to test pass rates. *Journal of econometrics*, 145(1-2):121–133.
- Pharoah, P., Stevenson, C., Cooke, R., and Stevenson, R. (1994). Prevalence of behaviour disorders in low birthweight infants. *Archives of disease in childhood*, 70(4):271–274.
- Romer, P. M. (1986). Increasing returns and long-run growth. *Journal of political economy*, 94(5):1002–1037.
- Roodman, D. (2011). Fitting fully observed recursive mixed-process models with cmp. *The Stata Journal*, 11(2):159–206.
- Rosales-Rueda, M. and Triyana, M. (2019). The persistent effects of early-life exposure to air pollution evidence from the indonesian forest fires. *Journal of Human Resources*, 54(4):1037–1080.
- Schultz, T. W. (1961). Investment in human capital. *The American economic review*, 51(1):1–17.
- Shrestha, R. (2019). Early life exposure to air pollution, cognitive development, and labor market outcome. *Asian Economic Papers*, 18(2):77–95.
- State Council (1998). Official reply to the state council concerning acid rain control areas and sulfur dioxide pollution control areas. Available at <http://www.asianlii.org/cn/legis/cen/laws/orotsccarcaasdpca1016/>.
- State Environmental Protection Agency (SEPA) (1996). The report on environmental quality in 1991-1995.
- Sun, Q. (2019). Estimating the earnings returns to exam-measured unobserved ability in china’s urban labor market: Evidence for 2002–2013. *China Economic Review*, 53:180–190.
- Sunyer, J. and Dadvand, P. (2019). Pre-natal brain development as a target for urban air pollution. *Basic & clinical pharmacology & toxicology*, 125:81–88.
- Tanaka, S. (2015). Environmental regulations on air pollution in china and their impact on infant mortality. *Journal of health economics*, 42:90–103.
- Tang, H.-l., Liu, J.-m., and Wu, J.-g. (2020). The impact of command-and-control environmental regulation on enterprise total factor productivity: A quasi-natural experiment based on china’s “two control zone” policy. *Journal of Cleaner Production*, 254:120011.

- The World Bank (2017). World bank open data. Available at: https://data.worldbank.org/indicator/SE.XPD.TOTL.GD.ZS?most_recent_value_desc=true.
- Wooldridge, J. M. (2010). *Econometric analysis of cross section and panel data*. MIT press.
- Wooldridge, J. M. (2019). Correlated random effects models with unbalanced panels. *Journal of Econometrics*, 211(1):137–150.
- Yang, J., Cao, D., Ge, C., and Gao, S. (2002). Air pollution control strategy for china's power sector. *Chinese Academy for Environmental Planning, Beijing, China*.
- Zhang, X., Chen, X., and Zhang, X. (2018). The impact of exposure to air pollution on cognitive performance. *Proceedings of the National Academy of Sciences*, 115(37):9193–9197.
- Zhang, X., Zhang, X., and Chen, X. (2017). Happiness in the air: How does a dirty sky affect mental health and subjective well-being? *Journal of environmental economics and management*, 85:81–94.
- Zheng, S., Wang, J., Sun, C., Zhang, X., and Kahn, M. E. (2019). Air pollution lowers chinese urbanites' expressed happiness on social media. *Nature Human Behaviour*, 3(3):237–243.
- Zivin, J. G., Liu, T., Song, Y., Tang, Q., and Zhang, P. (2020). The unintended impacts of agricultural fires: Human capital in china. *Journal of Development Economics*, 147:102560.

Appendix

3.A The Two Control Zones locations

Figure 3.A.1: The Two Control Zones Locations



Source: China Atlas of Population and Environment (1990-1999)
(All China Data Center)

3.B Data construction

3.B.1 Counties' TCZ designation

We respect the following rules in identifying TCZ treatment and control counties:

- We consider the name, area and divisional status (either district, county-level city, or county) as of 1998 for each location in CHIP13.
- Third level administrative locations explicitly listed as TCZ in the official document or which belong to prefectures that are listed as TCZ are assigned the TCZ status.
- All other third level administrative locations are assigned the non-TCZ status.

3.B.2 Pollution data

Pollution data is extracted using a polygon shapefile with the third-level administrative divisions of China as of 2015 (Hijmans, R. and University of California, Berkeley, Museum of Vertebrate Zoology, 2015). We consider the following rules in treating the pollution data:

- Changes in names and divisional status are considered, in order to get the right data for the right years.
- When a location is merged into another one, we use data on the newly merged area. One exception is the data used for Qijiang district which is the merged area of Qijiang county and Wansheng district in 2011. We use pollution data for Qijiang County as it is the only available data.
- when a location is divided into two different locations, I consider the new location. As we are interested in the concentration of air pollutants, smaller areas allows to have a better measure of these concentrations. However, due to data availability problem, the data for the area before division is used in some cases.

3.B.3 Income and demographic data

For the county level socioeconomic data, we consider the following rules:

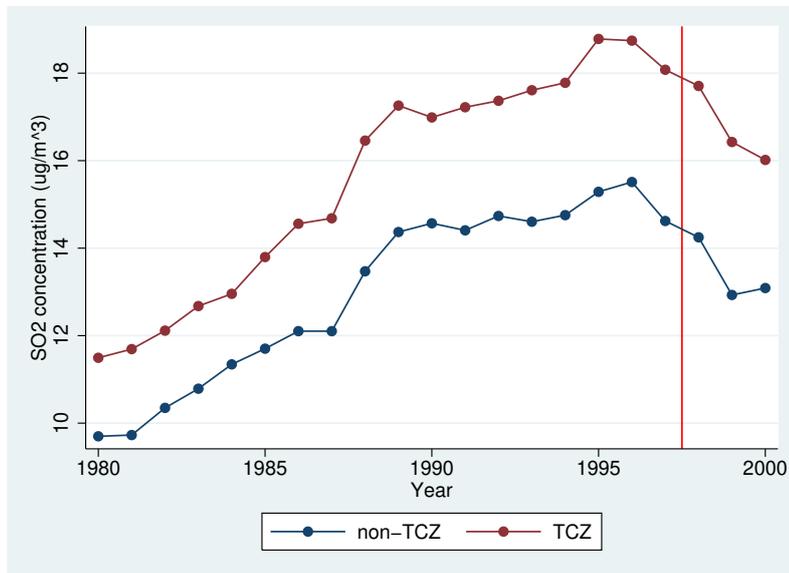
- Changes in names and divisional status are considered, in order to get the right data for the right years.

- When a location is merged into another one, the sum of the two locations is used, even in years of birth when the 2 locations are still independent. This is because we cannot, from the CHIP13 data, distinguish who is from which location. In cases where we are unable to get data for one of the two locations, we use data for only one location considering individuals born in the second location as originally born in the first one.
- When a location is divided into two different locations, I use data from the original one location before division if division happened after the year of birth of the individuals (which is the case for the whole sample, all divisions in our sample happened after 1999).
- Some counties have incomplete data on GDP per capita and total population, requiring us to interpolate the missing data.
- Because of data availability, Gross Regional Product per capita was used for counties and districts of Jiangsu province and for some districts of Yunnan province.
- We deflate GDP data by province-year CPI, taking Beijing-1998 as the base province-year. For the few missing values of provincial CPI, we use China's national CPI (1998, being the base year).
- Socioeconomic data for Beijing municipality at the third level administrative division is not available. Therefore, we allocate to each district from Beijing the same municipality level socioeconomic data.

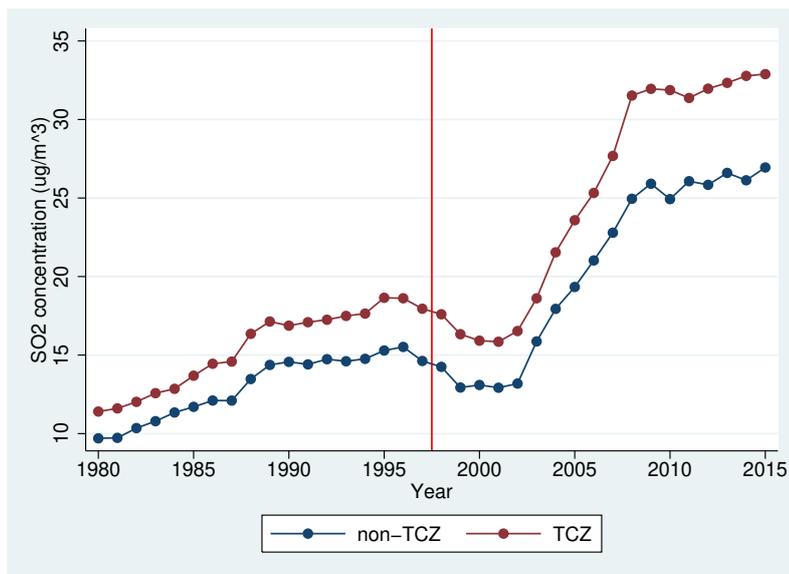
3.C Data analysis

Figure 3.C.1: Trends in SO₂ concentrations by TCZ status

(a) Panel A



(b) Panel B



Notes: These figures plot the trends of SO₂ ($\mu\text{g}/\text{m}^3$) between TCZ and non-TCZ counties. The annual means are calculated using all counties included in the CHIP13 urban and rural surveys and that have available pollution data at the county level. Panel A covers variations in trends between 1980 and 2000, while panel B covers that between 1980 and 2015. The red vertical line indicates the timing of TCZ policy implementation in January 1998, located between the annual average values of 1997 and 1998.

Table 3.C.1: Difference in characteristics by TCZ status before 1998

	(1)
	1992-1997
Male	-0.0387 (0.0358)
Han	0.236 (0.232)
Number of siblings	-0.218* (0.118)
Urban <i>hukou</i>	0.395*** (0.101)
Father's years of education	1.026*** (0.216)
Mother's years of education	1.474*** (0.287)
Mother's age at birth	0.0265 (0.209)
Father's age at birth	0.354 (0.258)
Total precipitation	311.6*** (82.80)
Average temperature	2.775*** (0.613)
Population (10000 persons)	0.0176 (0.123)
GDP per capita	0.636*** (0.156)

Notes: Each entry in this Table is the coefficient on the TCZ variable from a separate regression of each of the respective variables on the TCZ indicator (=1 if county is designated as TCZ) and year of birth fixed effects. Regressions are estimated using individual micro-data for the years before the TCZ implementation (1992-1997). Note that outliers created due to the linear interpolation of GDP per capita and Population (10000 persons) variables are dropped when running the regressions for these variables. Standard errors in parentheses are clustered by county. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3.C.2: Effect of TCZ implementation in the year of birth on long-term educational outcomes

	(1)	(2)	(3)
	High quality high school	Academic high school	Qualify for high school
TCZxPost	1.012*** (0.361)	1.299** (0.531)	0.206 (0.417)
Male	-0.114 (0.126)	-0.063 (0.159)	-0.457*** (0.118)
Han	0.486 (0.333)	0.050 (0.367)	-0.263 (0.239)
Number of siblings	0.082 (0.099)	-0.011 (0.100)	-0.185*** (0.070)
Urban hukou	0.281 (0.203)	0.014 (0.218)	0.607** (0.266)
Father's years of education	0.111* (0.065)	-0.001 (0.090)	0.063 (0.062)
Mother's years of education	-0.105 (0.072)	-0.022 (0.106)	0.028 (0.067)
Mother's age at birth	0.038 (0.026)	0.058* (0.034)	0.037 (0.023)
Father's age at birth	-0.021 (0.028)	-0.059* (0.032)	-0.011 (0.020)
Never schooled (Father)	0.444 (0.994)	-1.649 (1.487)	-9.174*** (1.156)
Elementary school (Father)	0.296 (0.605)	-1.605 (0.978)	-8.741*** (0.791)
Middle school (Father)	0.065 (0.415)	-1.564** (0.741)	-8.742*** (0.631)
Secondary school (Father)	-0.059 (0.270)	-0.751 (0.592)	-8.580*** (0.555)
University (Father)	<i>ref</i>	<i>ref</i>	<i>ref</i>
Never schooled (Mother)	-2.535** (1.038)	0.002 (1.538)	-1.022 (0.980)
Elementary school (Mother)	-2.233*** (0.714)	-0.868 (1.020)	-1.216* (0.723)
Middle school (Mother)	-1.811*** (0.501)	-0.809 (0.786)	-0.720 (0.572)
Secondary school (Mother)	-0.765** (0.319)	-0.166 (0.582)	-0.422 (0.459)
University (Mother)	<i>ref</i>	<i>ref</i>	<i>ref</i>
Total precipitation	0.000 (0.001)	0.003 (0.002)	-0.001* (0.001)
Total precipitation squared	-0.000 (0.000)	-0.000* (0.000)	0.000* (0.000)
Nbr days with 33<max temp<39	0.018 (0.044)	0.023 (0.069)	0.030 (0.036)
Nbr days with 40<max temp<49	0.008 (0.036)	-0.170*** (0.052)	-0.006 (0.042)
Nbr days with 50<max temp<59	-0.002 (0.037)	0.062 (0.063)	0.069* (0.035)
Nbr days with 60<max temp<69	0.069** (0.031)	0.116** (0.049)	-0.018 (0.028)
Nbr days with 70<max temp<79	0.042 (0.034)	0.140** (0.059)	0.010 (0.045)
Nbr days with 80<max temp<89	-0.023 (0.032)	-0.015 (0.044)	-0.019 (0.038)
Nbr days with 90<max temp<99	0.023 (0.036)	0.087* (0.044)	0.032 (0.041)
Nbr days with max temp>100	-0.001 (0.015)	0.030 (0.033)	-0.009 (0.024)
Population (10000 persons)	1.460* (0.839)	-1.937 (1.340)	0.454 (0.881)
GDP per capita	0.053 (0.344)	-0.359 (0.809)	-0.115 (0.364)
County fixed effects	Yes	Yes	Yes
ProvinceXyears fixed effects	Yes	Yes	Yes
Observations	939	709	1126
Pseudo R ²	0.260	0.282	0.257

Notes: See notes to Table 3.6.1.

Table 3.C.3: Effect of TCZ implementation on long-run education outcomes by year of birth

	(1)	(2)	(3)
<i>Panel A. High quality high school</i>			
1992 vs 1997	0.073	0.081	[-0.232, 0.085]
1993 vs 1997	-0.031	0.078	[-0.121, 0.184]
1994 vs 1997	-0.072	0.085	[-0.094, 0.238]
1995 vs 1997	-0.067	0.077	[-0.085, 0.218]
1996 vs 1997	0.020	0.075	[-0.168, 0.128]
1998 vs 1997	0.053	0.099	[-0.142, 0.248]
1999 vs 1997	0.322	0.258	[-0.185, 0.828]
<i>Panel B. Academic high school</i>			
1992 vs 1997	0.026	0.119	[-0.259, 0.207]
1993 vs 1997	0.012	0.095	[-0.199, 0.174]
1994 vs 1997	0.009	0.102	[-0.210, 0.191]
1995 vs 1997	-0.062	0.081	[-0.096, 0.221]
1996 vs 1997	-0.020	0.089	[-0.154, 0.194]
1998 vs 1997	0.091	0.098	[-0.100, 0.282]
1999 vs 1997	0.509*	0.276	[-0.031, 1.049]
<i>Panel C. Qualify for high school</i>			
1992 vs 1997	0.065	0.073	[-0.209, 0.078]
1993 vs 1997	0.012	0.073	[-0.155, 0.130]
1994 vs 1997	0.005	0.077	[-0.155, 0.145]
1995 vs 1997	0.096	0.076	[-0.245, 0.052]
1996 vs 1997	0.090	0.079	[-0.244, 0.065]
1998 vs 1997	0.052	0.099	[-0.141, 0.246]
1999 vs 1997	0.605***	0.226	[0.162, 1.049]

Notes: We compute, for each regression of Eq. (3.4) for the different dependent variables, the average marginal effects (AMEs) on the interactions between birth year indicators and the indicator for TCZ status. Each panel of this Table presents regression pairwise comparisons of the AMEs, in Column (1). 1992 vs 1997 corresponds to $(AME_{1992} - AME_{1997})$, 1993 vs 1997 corresponds to $(AME_{1993} - AME_{1997})$, 1994 vs 1997 corresponds to $(AME_{1994} - AME_{1997})$, 1995 vs 1997 corresponds to $(AME_{1995} - AME_{1997})$, 1996 vs 1997 corresponds to $(AME_{1996} - AME_{1997})$, 1998 vs 1997 corresponds to $(AME_{1998} - AME_{1997})$, 1999 vs 1997 corresponds to $(AME_{1999} - AME_{1997})$. Standard errors, clustered by county, are presented in Column (2) and their associated 95% confidence intervals in Column (3). * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3.C.4: Balancing test by TCZ status

	Trend difference	
	1992-1999	1996-1999
Male	0.040 (0.116)	0.251* (0.140)
Han	0.304 (0.444)	-0.101 (0.739)
Number of siblings	-0.121* (0.066)	-0.063 (0.074)
Urban hukou	-0.092 (0.193)	0.126 (0.230)
Father's years of education	0.130 (0.228)	0.045 (0.273)
Mother's years of education	-0.261 (0.287)	-0.074 (0.302)
Mother's age at birth	0.002 (0.305)	0.048 (0.379)
Father's age at birth	0.290 (0.301)	0.048 (0.395)
Total precipitation	84.70* (44.23)	56.14 (34.51)
Average temperature	0.064 (0.072)	0.067 (0.075)
Population (10000 persons)	0.012 (0.024)	0.003 (0.015)
GDP per capita	0.082 (0.066)	0.054 (0.044)

Notes: The estimates are that of the coefficients of the interaction term of TCZ indicator and a Post indicator (=1 for 1998 and 1999). Separate regressions are estimated while using each of the respective variables as the dependent variable based on Eq. (3.3). Note that outliers created due to the linear interpolation of GDP per capita and Population (10000 persons) variables are dropped when running the regressions for these variables. Column (1) reports results using all those born between 1992 and 1999, while column (2) reports results for those born between 1996 and 1999. See notes to Table 3.6.1.

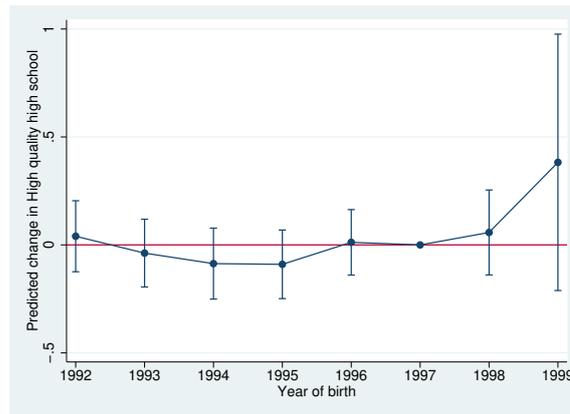
Table 3.C.5: Effect of TCZ implementation on long-run education outcomes by year of birth (CRE)

	(1)	(2)	(3)
<i>Panel A. High quality high school</i>			
1992 vs 1997	0.110*	0.066	[-0.240, 0.021]
1993 vs 1997	0.012	0.075	[-0.159, 0.136]
1994 vs 1997	-0.057	0.085	[-0.109, 0.223]
1995 vs 1997	-0.021	0.073	[-0.123, 0.165]
1996 vs 1997	0.017	0.073	[-0.160, 0.126]
1998 vs 1997	0.052	0.097	[-0.141, 0.245]
1999 vs 1997	0.195	0.300	[-0.393, 0.783]
<i>Panel B. Academic high school</i>			
1992 vs 1997	0.017	0.095	[-0.203, 0.168]
1993 vs 1997	0.073	0.082	[-0.234, 0.087]
1994 vs 1997	0.044	0.092	[-0.223, 0.136]
1995 vs 1997	-0.019	0.080	[-0.137, 0.175]
1996 vs 1997	-0.072	0.098	[-0.120, 0.264]
1998 vs 1997	0.139*	0.081	[-0.020, 0.298]
1999 vs 1997	0.530*	0.298	[-0.053, 1.114]
<i>Panel C. Qualify for high school</i>			
1992 vs 1997	0.116*	0.064	[-0.241, 0.009]
1993 vs 1997	0.038	0.060	[-0.157, 0.080]
1994 vs 1997	0.057	0.063	[-0.180, 0.066]
1995 vs 1997	0.114**	0.058	[-0.227, -0.001]
1996 vs 1997	0.119*	0.063	[-0.242, 0.005]
1998 vs 1997	0.046	0.079	[-0.109, 0.202]
1999 vs 1997	0.620***	0.203	[0.221, 1.019]

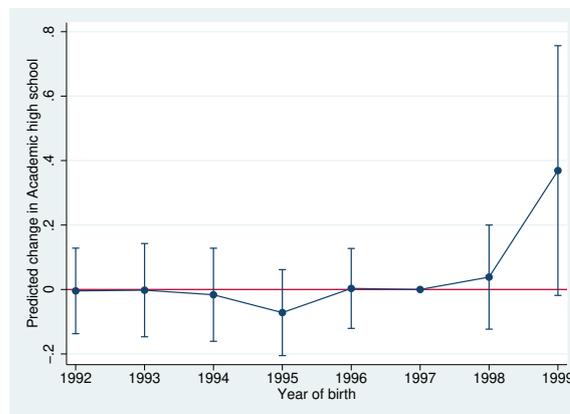
Notes: See notes to Table 3.C.3.

Figure 3.C.2: Effect of TCZ implementation on long-run education outcomes by year of birth (LPM)

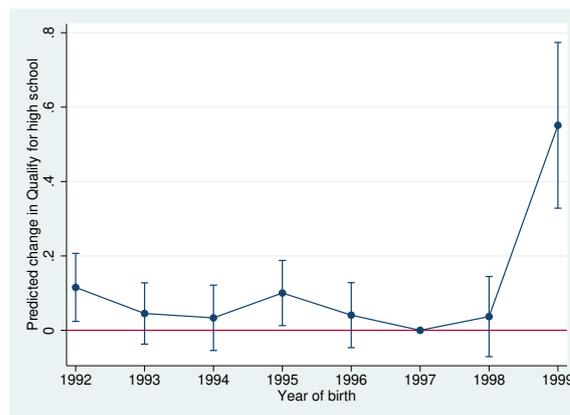
(a) High quality high school



(b) Academic high school



(c) Qualify for high school



Notes: This figure presents regression coefficients, from Eq. (3.4). We plot, for each outcome, indicated in the subheadings, the coefficients on the interactions between birth year indicators and the indicator for TCZ status, and their associated 90% Confidence Interval. The coefficient on the interaction between TCZ and birth year 1997 is normalized to zero. Standard errors are clustered by county.

Table 3.C.6: Effect of TCZ Implementation in the year of birth on long-term cognitive outcomes, LPM

	(1)	(2)	(3)
	High quality high school	Academic high school	Qualify for high school
TCZxPost	0.242** (0.106)	0.154* (0.089)	0.039 (0.066)
Child characteristics	Yes	Yes	Yes
Parents characteristics1	Yes	Yes	Yes
Parents characteristics2	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes
County characteristics	Yes	Yes	Yes
County fixed effects	Yes	Yes	Yes
ProvinceXyears fixed effects	Yes	Yes	Yes
Observations	1005	1005	1539
R ²	0.338	0.335	0.298

Notes: This table reports regression coefficients from 3 separate regressions. Cluster robust standard errors are shown in parentheses. See notes to Table 3.6.1.

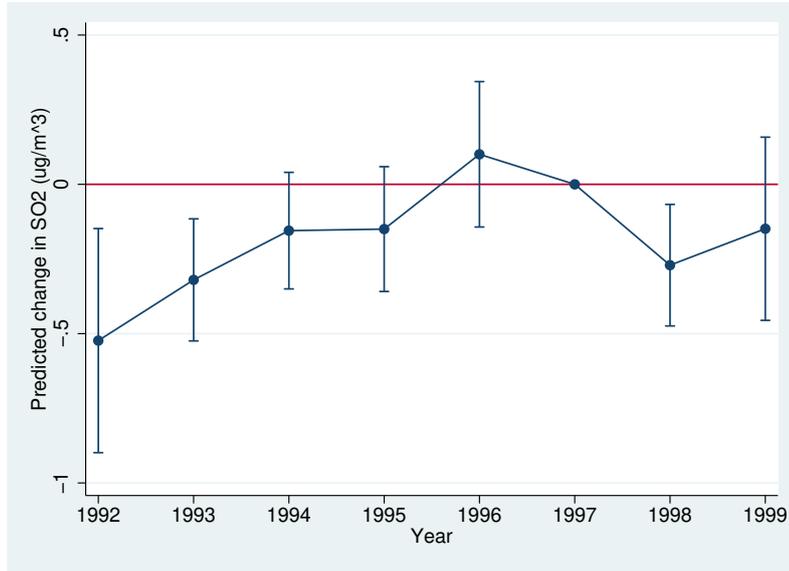
Table 3.C.7: Heterogeneity in the TCZ effects across Subpopulations (LPM)

	(1)	(2)	(3)
	High quality high school	Academic high school	Qualify for high school
<i>Panel A. Boys and girls</i>			
Boys	0.293** (0.128)	0.026 (0.173)	0.135 (0.103)
Observations	522	522	806
Girls	-0.202 (0.214)	0.120 (0.158)	0.001 (0.097)
Observations	483	483	733
<i>Panel B. High and low education of father</i>			
High father's education	0.064 (0.129)	0.080 (0.108)	-0.069 (0.069)
Observations	559	559	783
Low father's education	0.875*** (0.280)	0.283 (0.270)	0.060 (0.116)
Observations	446	446	756
<i>Panel C. High and low education of mother</i>			
High mother's education	0.093 (0.141)	0.010 (0.117)	-0.104 (0.069)
Observations	498	498	657
Low mother's education	0.367 (0.318)	0.226 (0.199)	0.126 (0.130)
Observations	507	507	882
Child characteristics	Yes	Yes	Yes
Parents characteristics1	Yes	Yes	Yes
Parents characteristics2	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes
County characteristics	Yes	Yes	Yes
County fixed effects	Yes	Yes	Yes
ProvinceXyears fixed effects	Yes	Yes	Yes

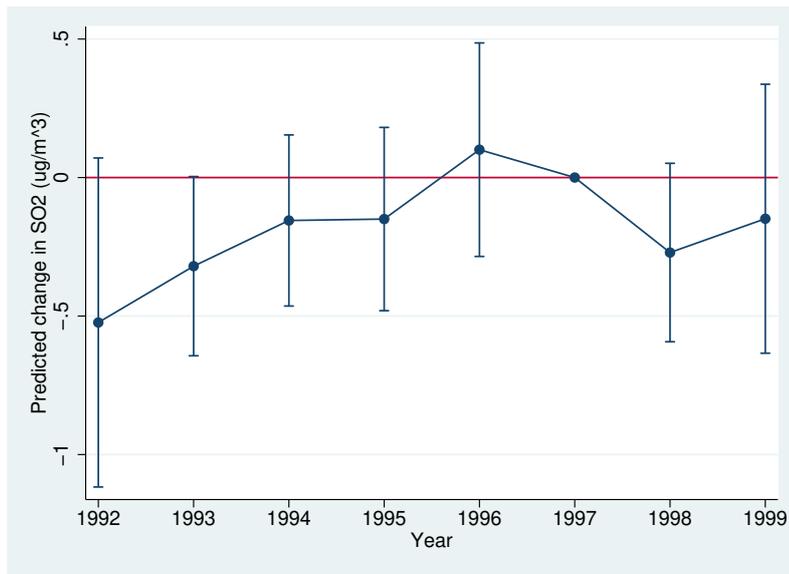
Notes: Each entry reports the difference-in-differences estimates using LPM regressions. High/low father's and mother's education is defined as having a number of years of schooling that is above or equal/below 9. See notes to Table 3.6.1.

Figure 3.C.3: Effect of TCZ implementation on county SO₂ concentration by year

(a) Panel A



(b) Panel B



Notes: Each panel of this figure presents regression coefficients from the distributed lag model in Eq. (3.4), where the dependent variable used is $SO_{2ct,t}$, the annual SO₂ concentration by county. The sample used covers all counties used to estimate Eq. (3.5), and that have available pollution data at the county level only. We plot the coefficients on the interactions between birth year indicators and the indicator for TCZ status, and their associated 90% (Panel A) or 99% (Panel B) Confidence Interval. The coefficient on the interaction between TCZ and birth year 1997 is normalized to zero. Standard errors are clustered by county.

Table 3.C.8: TCZ effects in rural areas

	(1)	(2)	(3)
	High quality high school	Academic high school	Qualify for high school
<i>Panel A. CRE</i>			
TCZxPost	0.408 (0.612)	0.896* (0.506)	0.285 (0.379)
Observations	615	563	1004
Pseudo R ²	0.173	0.243	0.186
<i>Panel B. LPM</i>			
TCZxPost	0.390* (0.206)	0.193 (0.172)	0.102 (0.120)
Observations	638	638	1084
R ²	0.376	0.419	0.311
Child characteristics	Yes	Yes	Yes
Parents characteristics1	Yes	Yes	Yes
Parents characteristics2	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes
County characteristics	Yes	Yes	Yes
ProvinceXyears fixed effects	Yes	Yes	Yes

Notes: Each entry reports the DID estimate, using CRE regressions (Panel A) and LPM regressions (Panel B). County fixed effects are included in the LPM estimations. See notes to Table 3.6.2 and Table 3.6.1.

Table 3.C.9: Effect of exposure to air pollution in the year of birth on long-term cognitive outcomes: PSM-DID method

	(1)	(2)	(3)
	High quality high school	Academic high school	Qualify for high school
<i>Panel A. Fixed effects model</i>			
TCZxPost	2.215*** (0.674)	3.167*** (0.845)	0.337 (0.533)
Observations	511	322	611
Pseudo R ²	0.288	0.337	0.271
<i>Panel B. CRE model</i>			
TCZxPost	0.622 (0.398)	1.019** (0.476)	0.597 (0.392)
Observations	583	522	829
Pseudo R ²	0.190	0.309	0.259
TCZxPost (differences in probability)	0.143*** (0.049)	0.165*** (0.051)	0.065 (0.113)
<i>Panel C. LPM</i>			
TCZxPost	0.362** (0.150)	0.277** (0.115)	0.055 (0.080)
Observations	620	620	1012
R ²	0.425	0.469	0.347
Child characteristics	Yes	Yes	Yes
Parents characteristics1	Yes	Yes	Yes
Parents characteristics2	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes
County characteristics	Yes	Yes	Yes
ProvinceXyears fixed effects	Yes	Yes	Yes

Notes: This table reports regression coefficients from 9 separate regressions. County fixed effects are used in estimations of Panel A and Panel C. TCZxPost reports the DID coefficients from the estimations, and TCZxPost (differences in probability) reports the average DID in probability of outcomes (pairwise comparisons of the average marginal effects in TCZ and non-TCZ counties). See notes to Table 3.6.2 and Table 3.6.1.

General Conclusion

Along the course of their lives, children undergo different investments in their human capital, particularly in the form of parental monetary and time investments and government interventions. This dissertation has theoretically and empirically explored questions related to two different investments in child human capital: parents' migration where children are left behind and government environmental policies. These two activities, the former as a time disinvestment in children's human capital and the latter as an investment in early-life conditions, are affected and/or motivated by riskiness. In this work, we investigate three main questions. The first focuses on how different risks affect migration spells of parents with left-behind children, while the second is interested with potential determinants of using parents' migration as a risk-coping strategy by households. The last one explores the effects of early-in-life government interventions, implemented to deal with risk factors for children's human capital deterioration.

A first important dimension is that children may be involved in different decision-making structures where either the parent, the household or the country is the investment decision maker. Moreover, even though risk is always part of the decision-making process throughout the dissertation, the role played by this measure differs substantially along the chapters. Chapter 1 posits a parental model of migration duration decision, where parents are faced with different types of risks on income, the children's human capital and accumulated savings. Human capital of children in the model is used as the decision parameter in determining migration spells. Chapter 2 posits the household, a larger unit of related people, as a collective decision maker: the household pools and shares resources as well as decision-making, and maximizes a unified utility function defined over their earnings and the children's human capital. In the absence of formal insurance and credit markets, households turn to migration as a way to diversify their income in the presence of an aggregate agricultural risk. Child human capital is part of the risk-coping strategy determined by the household. More precisely, the expected effects of migration on the children's human capital affect the decision to send a parent for migration, as a risk-coping

strategy. Chapter 3 focuses on government policy-making that aim to deal with human capital risk-factors.

Using a theoretical model of parental migration with left-behind children, the dissertation shows how risk-averse migrant parents do not necessarily react to changes in the riskiness of incomes, children's human capital and accumulated savings. Only the migration duration of parents with particular features of their risk preferences, in terms of higher order risk attitudes, is affected by changes in risks. The sign of these effects is also shown to be determined by the nature of the considered risk preferences. Using household income and migration coupled with rainfall data, the dissertation also highlights that rural Chinese households with negative expected income differentials are less likely to use migration as a way to diversify their income, in the face of an aggregate income risk. This effect is, however, decreasing with the level of the income differential. Particularly, it starts dropping when the expected income of the household with a migrant parent is around 1.32 to 1.38 their expected income when they do not have a migrant parent. For these rural households, who care not only about their income but also about the children's human capital, each additional monetary unit is more desirable for them when children have lower school test scores. If rural-urban income differential is positive for these households, those with children poorly performing at school may be more likely to send a parent for migration, compared to households with better performing children. Last, focusing on rural and urban Chinese children exposed to the implementation of an environmental policy during their first year of birth reveals long-term positive effects on their educational performance 15 years later. Particularly, the probability to get better test scores and join a higher quality high school increases by about 12 percentage points, while the probability to choose an academic high school, instead of a specialized/vocational high school increases by about 18 percentage points.

The main takeaway of the dissertation relates to the importance of understanding the determinants and the consequences of parents, households and policy makers' decisions with respect to human capital accumulation of children, in the presence of riskiness. Along this line, a lot remains to be done despite the substantial work on the human capital investment literature since the pioneering works of Becker, and the dissertation offers some insights for future research. First, it introduces two models of migration decision-making by parents and households in Chapters 1 and 2. A drawback of these frameworks is that they consider migration in isolation to other decisions. A fruitful area for future research would be to integrate other economic decisions simultaneously with the migration decision, such as savings or monetary investments in children. Indeed, the

expected temporariness of the parent's migration may imply changes in other economic choices, particularly in the presence of risk, while the riskiness of agricultural incomes may stimulate the use of different risk-coping strategies in addition to migration. Second, Chapter 1 stresses the key role of the way parents perceive each additional monetary unit when their children's human capital decreases, in determining migration duration choices. Future research may be concerned with embedding this feature of the parents' preferences within models of migration behavior. Even though Chapter 2 provided an empirical approach to measure this preference, more sophisticated experimental methods may also be used. Last, a natural extension to Chapter 3 would be to enlarge the analysis to longer-term labor market outcomes as effects of exposure to the implementation of environmental policies in developing countries, in order to delve deeper into the persistence of these effects over larger periods of time.