Impacts of off-farm employment on groundwater irrigation in North China

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ONLINE APPENDIX

Appendix 1. Conceptual framework on pathways through which off-farm employment influences irrigation water use

The New Economics of Labor Market (NELM) (Stark and Bloom, 1985; Rozelle *et al*., 1999; Taylor *et al*., 2003) hypothesizes that off-farm employment could affect agricultural productivity where credit and/or time constraints bind since migration and remittances could affect how much capital and labor a household can allocate to agricultural production. Hypotheses implied by the NELM theory are often tested with data from less developed countries where labor and/or credit markets are missing or imperfect. Some studies have found that a reduction in family labor would have affected agricultural production since labor lost to migration cannot be effectively substituted by hired labor, however, remittances compensated for lost labor to some extent (Rozelle *et al*., 1999; Taylor *et al*., 2003).

Following Wang *et al*. (2014) and de Brauw and Giles (2012), appendix 2 uses a simple household utility maximization model to illustrate the pathways through which off-farm employment may affect irrigation water use and investment. The first pathway is often associated with the "lost-labor effect" (Taylor *et al*., 2003). When a household faces a time constraint, increasing off-farm employment would reduce the amount of time a household can spend on agricultural production and leisure, thus increasing the shadow value of time.[1] Even if rural households do hire labor to help out with field work, family labor and hired labor are not perfect substitutes. For example, family labor will make efforts to monitor water flows in order to make sure the field is adequately irrigated and the pump is turned off once irrigation is complete. Even if family labor and hired labor apply the same amount of irrigation water, hired labor may irrigate with massive flows in a short time instead of

[1] The first pathway would disappear if off-farm employment opportunity were unlimited. In this case, households would allocate time to off-farm employment until the marginal return to the last unit of off-farm labor equals the marginal return to the farm labor. Then the shadow value of the time is exogenously determined by the wage rate in the off-farm labor market. Most empirical studies support the assumption that off-farm employment opportunity is limited due to factors such as institutional barriers or lack of information about off-farm labor markets (e.g., Wang *et al*., 2014). One typical example of institutional barriers to migration is China's residential registration (*Hukou*) system, which requires rural residents to obtain temporary residence permits to work outside where they are registered.

irrigating with more even flows in a longer time. These differences would generate different crop yields. In our survey, nearly all farmers reported that they spent significant amounts of time monitoring the irrigation process to make sure their fields were well irrigated.

The amount of irrigation water applied may change due to a higher shadow value of time. The change depends on whether labor and water are complements or substitutes in agricultural production. A certain amount of labor is needed to apply irrigation water during the irrigation season. So labor and water are complements, at least for the lower range of the labor input. This is particularly true for irrigation methods such as basin irrigation and furrow irrigation, which are relatively more labor intensive than other methods such as sprinkler irrigation (Zuo, 1997). In rural China, basin irrigation and furrow irrigation are still the main methods of irrigation (Blanke *et al*., 2007). So for most rural households, irrigation water and labor are likely to be complements during the irrigation season. In this case, off-farm employment will likely reduce irrigation.

However, irrigation water and labor can also be substitutes. When water becomes scarcer (the shadow price of water increases), more labor may be spent to use more water more effectively (Cai *et al*., 2008). In this sense, migration and local off-farm employment may divert labor away from water-saving efforts and result in higher water use. For example, the shortage of labor was cited as one of the reasons for not adopting soil conservation practices in the Nile Basin of Ethiopia (Di Falco *et al*., 2011). In the case of irrigation water, if less labor is available during the irrigation season, irrigation water use may increase because crops are not monitored to make sure water is only applied when needed, or pumps are not turned off when sufficient water has been applied.

When off-farm employment reduces labor available for agriculture production, households may also respond by reallocating labor among different irrigation-related activities. Practices such as converting basin irrigation to furrow irrigation or increasing the number of furrows can reduce irrigation application rates by reducing seepage losses. These practices require labor inputs but are not capital intensive and thus can be used by individual households. Digging more furrows can reduce the amount of labor needed to apply water during the irrigation season. If a household makes such reallocations, labor loss due to off-farm employment affects irrigation application rates through both the substitution effects in water-saving efforts and the complementarity between labor and water in irrigation application. The volume of water applied can go up or down as a result. A few other studies have also observed the reallocation of labor as a response to the lost labor effect. For example, Wang *et al*. (2014) find that rice-producing Chinese households respond to labor lost to migration by reallocating labor from leisure and other low-return activities to rice production.

The second pathway through which off-farm employment may affect irrigation water use and investment is often associated with the "income effect" (Du *et al*., 2005). The household also faces a credit constraint and thus cannot borrow beyond current agricultural capital and income from farming and off-farm employment. An increase in off-farm income would relax the constraint and so the show value of capital falls. The household is likely to respond by accumulating more agricultural capital and increasing the stock of agricultural assets such as machinery, wells and better irrigation technologies. The magnitude of the increase depends on the discount factor. If the household has a high discount factor, then it is more likely to allocate more of the additional income from off-farm employment to current consumption. The magnitude also depends on how much additional agricultural capital can boost agricultural productivity. Investing in irrigation may still bring high returns. Irrigation improves crop yields. For example, Huang *et al*. (2006) finds that ceteris paribus, switching from rainfed to irrigation increases wheat yield by about 18 per cent. Irrigation also maintains and augments soil quality (e.g., Lichtenberg, 1989). There is some evidence that credit constraint has limited irrigation use. In our sample area, among the households who had access to groundwater but did not use it in the last growing season, 14.4 per cent reported that they did not use groundwater because they could not afford the cost of water. Income from off-farm employment could be used to finance the purchase of groundwater or new wells. Zhang *et al*. (2008) find that households with higher income are more likely to own wells and sell groundwater to other households. Additional income brought in by off-farm employment may also nudge farmers towards the adoption of irrigation technologies. For example, Zhou *et al*. (2008) find that household income is positively correlated with the probability of Chinese farmers adopting water saving technology for rice production.

In addition to boosting agricultural production, irrigation investment, either through higher share of irrigated land or higher irrigation efficiency, reduces the exposure of crop production to weather shocks such as droughts, a major source of production risk. Therefore, irrigation investment can reduce volatility in crop income. This benefit of irrigation investment is not captured in the simple model in appendix 1 but can be an important consideration for rural households. With the increased volatility in the non-farm labor market, farming has become the buffer against unemployment that migrants and local wage earners resort to. For example, during the global financial crisis, 49 million of the rural labor force were laid-off between October 2008 and April 2009 (Huang *et al*., 2011), a lot of whom returned to farming until they were able to find jobs. Gao and Jia (2007) also noticed an increasing trend of migrants returning to their home communities, especially after the mid-1990s.

It is difficult to separate the impact of the two pathways. One reason is that the substitution between labor and other inputs may affect irrigation water use. For example, the tight labor supply conditions in the US during the 1960s promoted the use of center pivot, which only used one-fourth as much labor as furrow irrigation did (Nieswiadomy, 1988). In this case, the substitution between labor and capital reduced water use. The effects of these two pathways is also entangled if leisure is a normal good, higher income increases demand for leisure, which would in turn further increase the shadow value of time. If households do not face credit constraints, the income effect would disappear. Then the lost-labor effect can be quantified empirically. Or if time constraints are not binding for households, then the income effect can be estimated. In the empirical analysis, we do not have ways to disentangle the two effects and can only examine the total effect of off-farm employment on irrigation water use and irrigation investment.

The comparative dynamics from the utility maximization problem do not produce clear predictions of the effects of off-farm employment on groundwater use or irrigation investment. The direction of the effects (positive or negative) depends on the characteristics of households (e.g., preferences for leisure, risk preferences), relationships among different inputs and between inputs and output, and whether time and/or credit constraints are binding. Ultimately, the impact of off-farm employment on groundwater use and irrigation investment is an empirical question.

Appendix 2. A simple household utility maximization model

The utility of a household in period t, $u(c_t, \varepsilon_t; \boldsymbol{\alpha})$, is a function of consumption, c_t, and time spent on leisure, ε_t. It is also influenced by household characteristics such as preferences and demographic composition, denoted by $\boldsymbol{\alpha}$. The household can generate income from crop production and off-farm employment. Crop output, $Q(l_t^a, x_t, \mathbf{I}_t; K_t)$, is produced using agricultural labor, l_t^a, water, x_t, and other inputs, $\mathbf{I}_t$. Agricultural productivity is determined by the level of agricultural capital, K_t. The household accumulates agricultural capital according to:

$$K_{t+1} \leq K_t + Q(l_t^a, x_t, \mathbf{I}_t; K_t) - r_t x_t - \mathbf{p}_t' \mathbf{I}_t + R(l_t^O; \boldsymbol{\beta}) - c_t, \qquad \text{(A1)}$$

where r_t is the unit cost of water and $\mathbf{p}_t$ is the vector of prices for other inputs. The price of crop output is normalized to one. The second, third and fourth terms on the right hand side of equation (A1) calculate the farming income. Income from off-farm employment, $R(l_t^O; \boldsymbol{\beta})$, is a function of the total amount of time household members spend on off-farm work, l_t^O, and a set of factors contained in the vector $\boldsymbol{\beta}$ that influence demand for off-farm labor, such as the conditions of local off-farm labor markets and the labor markets in migration destinations. The off-farm income is increasing and concave in l_t^O (Wang *et al*., 2014): As more time is allocated to off-farm employment, the marginal return to l_t^O decreases, since better-paying jobs are more difficult to find. The household's time constraint is expressed as:

$$l_t^O + l_t^a + \varepsilon_t \leq \bar{L}_t, \qquad \text{(A2)}$$

where $\bar{L}_t$ is the time endowment of the household.

The household maximizes the sum of utilities over time, subject to the constraints defined in equations (A1) and (A2):

$$Max\ u(c_t, \varepsilon_t; \boldsymbol{\alpha}) + \delta V_{t+1}(K_{t+1}, \bar{L}_{t+1}; \boldsymbol{\alpha}), \qquad \text{(A3)}$$

where δ is the discount factor and $V_{t+1}(K_{t+1}, \bar{L}_{t+1}; \boldsymbol{\alpha})$ is the value function that represents the maximized sum of future utilities, $\max_{\{c_s, \varepsilon_s\}} \sum_{t+1}^{\infty} \delta^{s-(t+1)} u_s(c_s, \varepsilon_s; \boldsymbol{\alpha})$. It is reasonable to assume that $V_{t+1}(K_{t+1}, \bar{L}_{t+1}; \boldsymbol{\alpha})$ increases and is concave in K_{t+1}. When maximizing utilities, the household makes its time allocation decisions jointly with its consumption and production decisions.

The maximization problem defined in equations (A1)–(A3) shows at least two possible pathways through which off-farm employment can affect irrigation water use and irrigation investment. The first pathway is through the effect of off-farm employment on the shadow value of time. Assuming interior solutions, one relationship between l_t^a and x_t implied by the necessary conditions of a utility maximization problem is:

$$\frac{\partial Q(l_t^a, x_t, \mathbf{I}_t; K_t) / \partial x_t}{\partial Q(l_t^a, x_t, \mathbf{I}_t; K_t) / \partial l_t^a} = \frac{r_t}{w_t^s}, \tag{A4}$$

where w_t^s is the shadow value associated with the time constraint in equation (A2). When w_t^s changes, households may respond by adjusting x_t. The adjustment depends on the relationship between labor and water in agricultural production as defined by $Q(l_t^a, x_t, \mathbf{I}_t; K_t)$.

The second pathway through which off-farm employment may affect irrigation water use and investment is through its effect on the shadow value of capital. Implicit in equation (A1) is the assumption that the household faces a credit constraint. An increase in off-farm income, $R(l_t^O; \boldsymbol{\beta})$, would relax the constraint defined in equation (A1) by the same amount and so the show value of capital, λ_t, associated with equation (1) falls. In the maximization problem defined in equations (A1)–(A3), the necessary condition regarding K_{t+1} is:

$$\delta \frac{\partial V_{t+1}(K_{t+1}, \bar{L}_{t+1}; \boldsymbol{\alpha})}{\partial K_{t+1}} = \lambda_t. \tag{A5}$$

Therefore, when λ_t decreases, the household is likely to respond by increasing K_{t+1}. The magnitude of the increase depends on the discount factor, δ. The magnitude also depends on

$\frac{\partial V_{t+1}(K_{t+1}, \bar{L}_{t+1}; \boldsymbol{\alpha})}{\partial K_{t+1}}$, which measures how much additional agricultural capital can increase the value function through its effects on improving agricultural productivity.

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Table A1. Alternative specifications of table 3, columns (1), (3) and (5)

	(1) Log of Total groundwater	(2) Log of Total irrigation hours	(3) Number of irrigations
Specification 1: Removed Prefer low risk technologies and Consider unexpected incidents			
% labor migrated	-0.115	-0.110	0.420
	(0.180)	(0.180)	(0.372)
% labor worked off-farm locally	0.0751	0.0491	-0.101
	(0.142)	(0.142)	(0.291)
Specification 2: Removed Prefer low risk technologies and Consider unexpected incidents Add two relative variables			
% labor migrated	-0.0655	-0.0561	0.500
	(0.182)	(0.181)	(0.371)
% labor worked off-farm locally	0.0740	0.0521	-0.149
	(0.143)	(0.143)	(0.290)
Number of relatives living in the village	0.00198**	0.00198**	0.00508***
	(0.000952)	(0.000949)	(0.00194)
Number of relatives migrated the past 10 years	-0.00321	-0.00471	0.0114
	(0.00729)	(0.00727)	(0.0148)
Specification 3: Add two relative variables			
% labor migrated	-0.0441	-0.0353	0.502
	(0.184)	(0.183)	(0.376)
% labor worked off-farm locally	0.0910	0.0684	-0.147
	(0.145)	(0.144)	(0.295)
Number of relatives living in the village	0.00196**	0.00196**	0.00507***
	(0.000955)	(0.000953)	(0.00195)
Number of relatives migrated the past 10 years	-0.00428	-0.00575	0.0114
	(0.00740)	(0.00738)	(0.0151)
Prefer low risk technologies	-0.0881	-0.0852	-0.0111
	(0.0998)	(0.0995)	(0.204)
Consider unexpected incidents	0.0287	0.0320	-0.0126
	(0.0798)	(0.0796)	(0.164)

Notes: Standard errors in parentheses. **, *** significant at 5% and 1%, respectively.
[a] Results on other control variables are largely consistent with those in table 3 and this are not reported for the sake of brevity.

Table A2. Alternative specifications of table 4, columns (1), (3), and (5)

	(1) Invested well	(2) Used one or more WST	(3) N furrows per mu
Specification 1: Removed Prefer low risk technologies and Consider unexpected incidents			
% labor migrated	0.0204	0.142	0.654
	(0.115)	(0.110)	(1.624)
% labor worked off-farm locally	0.0985	0.128	3.401***
	(0.0890)	(0.0858)	(1.263)
Specification 2: Removed Prefer low risk technologies and Consider unexpected incidents Add two relative variables			
% labor migrated	0.0210	0.130	-0.114
	(0.116)	(0.112)	(1.572)
% labor worked off-farm locally	0.0865	0.113	2.529**
	(0.0901)	(0.0869)	(1.219)
Number of relatives living in the village	0.000523	0.000111	0.00279
	(0.000604)	(0.000584)	(0.00820)
Number of relatives migrated the past 10 years	0.00373	0.00503	0.295***
	(0.00457)	(0.00441)	(0.0618)
Specification 3: Add two relative variables			
% labor migrated	0.0346	0.149	-0.120
	(0.116)	(0.113)	(1.584)
% labor worked off-farm locally	0.105	0.128	2.483**
	(0.0900)	(0.0876)	(1.233)
Number of relatives living in the village	0.000446	0.000112	0.00323
	(0.000598)	(0.000583)	(0.00820)
Number of relatives migrated the past 10 years	0.00339	0.00396	0.293***
	(0.00457)	(0.00444)	(0.0625)
Prefer low risk technologies	-0.0679	-0.0798	0.0818
	(0.0632)	(0.0615)	(0.865)
Consider unexpected incidents	-0.125**	0.0693	1.028
	(0.0504)	(0.0490)	(0.690)

Notes: Standard errors in parentheses. **, *** significant at 5% and 1%, respectively.
[a] Results on other control variables are largely consistent with those in table 4 and this are not reported for the sake of brevity.

Table A3. Alternative specifications of table 5, columns (1), (3), (5), (7) and (9)

	(1) Log of Output value	(2) Log of Output value per m^3 of water	(3) % wheat	(4) % corn	(5) Fallowed land
Specification 1: Removed Prefer low risk technologies and Consider unexpected incidents					
% labor migrated	0.0806	0.318*	0.00991	0.0410	0.148
	(0.124)	(0.189)	(0.0322)	(0.0330)	(0.0972)
% labor worked	0.0407	0.147	0.0178	0.0331	0.00972
off-farm locally	(0.0972)	(0.148)	(0.0250)	(0.0256)	(0.0755)
Specification 2: Removed Prefer low risk technologies and Consider unexpected incidents Add two relative variables					
% labor migrated	0.0916	0.254	0.0105	0.0436	0.146
	(0.126)	(0.191)	(0.0327)	(0.0336)	(0.0982)
% labor worked	0.0331	0.127	0.0171	0.0333	0.0249
off-farm locally	(0.0983)	(0.148)	(0.0254)	(0.0260)	(0.0761)
Number of relatives	0.000726	-0.00169*	0.0000533	0.0000999	-0.000667
living in the village	(0.000660)	(0.000997)	(0.000171)	(0.000175)	(0.000512)
Number of relatives	0.00186	0.00950	0.000193	-0.000178	-0.00459
migrated the past 10 years	(0.00496)	(0.00750)	(0.00129)	(0.00132)	(0.00386)
Specification 3: Add two relative variables					
% labor migrated	0.0823	0.210	0.0136	0.0450	0.130
	(0.128)	(0.192)	(0.0331)	(0.0339)	(0.0990)
% labor worked	0.0237	0.0852	0.0196	0.0340	0.0105
off-farm locally	(0.0998)	(0.150)	(0.0258)	(0.0264)	(0.0771)
Number of relatives	0.000750	-0.00162	0.0000531	0.000105	-0.000652
living in the village	(0.000662)	(0.000995)	(0.000171)	(0.000176)	(0.000513)
Number of relatives	0.00222	0.0116	0.0000235	-0.000279	-0.00379
migrated the past 10 years	(0.00504)	(0.00757)	(0.00131)	(0.00134)	(0.00391)
Prefer low risk technologies	0.0413	0.188*	-0.0128	-0.00490	0.0688
	(0.0695)	(0.104)	(0.0181)	(0.0185)	(0.0541)
Consider unexpected	0.0312	0.0123	0.0101	0.0158	-0.0178
incidents	(0.0555)	(0.0834)	(0.0144)	(0.0148)	(0.0431)

Notes: Standard errors in parentheses. * denotes significant at 10%.

[a] Results on other control variables are largely consistent with those in table 5 and this are not reported for the sake of brevity.

Table A4. Limited dependent variables

Specifications	Number of irrigations [a]		Invested well [b]		Use one or more WST [b]		Fallowed land [b]	
	(1). Table 3. (5)	(2). Appendix 3 Spec 3	(3). Table 4. (1)	(4). Appendix 4 Spec 3	(5). Table 4. (3)	(6). Appendix 4 Spec 3	(7). Table 5. (9)	(8). Appendix 5 Spec 3
% labor migrated	0.231	0.305	0.203	0.252	1.175	1.163	1.231	1.302
	(0.542)	(0.549)	(0.850)	(0.864)	(0.842)	(0.873)	(0.928)	(0.926)
% labor worked off-farm locally	-0.363	-0.377	1.046	1.000	1.243*	1.259*	-0.125	0.234
	(0.385)	(0.392)	(0.670)	(0.679)	(0.748)	(0.751)	(0.726)	(0.783)
Number of relatives living in the village		0.00348		0.00418		-0.00141		-0.0144
		(0.00366)		(0.00512)		(0.00524)		(0.00953)
Number of relatives migrated the past 10 years		0.00436		0.0251		0.0905		-0.113
		(0.0199)		(0.0348)		(0.0558)		(0.0814)
Number of people in household	0.171**	0.169**	0.173	0.162	0.149	0.115	0.0975	0.159
	(0.0691)	(0.0700)	(0.134)	(0.137)	(0.130)	(0.133)	(0.148)	(0.161)
Share of children in household	-0.749	-0.723	-2.355	-2.430	-2.050	-2.256	-1.623	-1.910
	(0.869)	(0.872)	(1.739)	(1.776)	(1.670)	(1.715)	(2.112)	(2.313)
Share of elderly in household	0.200	0.181	0.0306	-0.0517	0.115	0.0976	1.053	1.389
	(0.547)	(0.553)	(0.773)	(0.775)	(0.812)	(0.808)	(0.863)	(0.913)
Decision maker is male	0.585**	0.551**	0.329	0.268	0.899*	0.825*	-1.326**	-1.102**
	(0.263)	(0.272)	(0.464)	(0.472)	(0.460)	(0.474)	(0.535)	(0.562)
Age (years)	0.00129	0.00293	0.000548	0.00185	0.00518	0.00990	-0.0268	-0.0341
	(0.0115)	(0.0116)	(0.0203)	(0.0205)	(0.0214)	(0.0222)	(0.0253)	(0.0255)
Years of schooling	0.0539	0.0527	-0.0879	-0.0908	0.0873	0.0936	0.0708	0.111
	(0.0441)	(0.0433)	(0.0687)	(0.0694)	(0.0736)	(0.0741)	(0.0905)	(0.101)
Prefer low risk technologies	-0.172	-0.150	-0.758	-0.739	-0.660	-0.574	0.713	0.551
	(0.271)	(0.278)	(0.462)	(0.470)	(0.505)	(0.514)	(0.581)	(0.591)

Consider unexpected incidents	-0.0963	-0.0783	-0.932**	-0.934**	0.607	0.484	-0.350	-0.365
	(0.240)	(0.243)	(0.383)	(0.386)	(0.394)	(0.406)	(0.431)	(0.442)
Total land holding	-0.829***	-0.870***	0.115	0.116	0.119*	0.131*	-0.0922	-0.102
	(0.227)	(0.230)	(0.0786)	(0.0803)	(0.0664)	(0.0687)	(0.0944)	(0.101)
Number of plots	0.0793	0.0948	-0.0871	-0.0554	-0.259	-0.244	0.0614	-0.0194
	(0.0971)	(0.100)	(0.191)	(0.193)	(0.161)	(0.164)	(0.198)	(0.207)
Rate soil quality good	-0.627**	-0.632**	0.127	0.0989	1.141***	1.067**	0.134	0.272
	(0.259)	(0.268)	(0.398)	(0.401)	(0.436)	(0.445)	(0.473)	(0.484)
Electricity price	-1.442**	-1.378**			3.056	2.642	4.925*	5.822**
	(0.588)	(0.591)			(2.613)	(2.660)	(2.674)	(2.769)

Notes: Standard errors in parentheses. *, **, *** significant at 10%, 5% and 1%, respectively.

[a] Estimation method is ordered logit.

[b] Estimation method is conditional logit model grouped at the village level.