INCOME AND POPULATION GROWTH*

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Do populations grow as countries become richer? In this study we estimate the effects on population growth of shocks to national income that are plausibly exogenous and unlikely to be driven by technological change. For a panel of over 139 countries spanning the period 1960–2007, we interact changes in international oil prices with countries' average net-export shares of oil in GDP. Controlling for country and time fixed effects, we find that this measure of oil price induced income growth is positively associated with population growth. The IV estimates indicate that a 1 percentage point increase in GDP *per capita* growth over a 10-year period increases countries' population growth by around 0.1 percentage points. Furthermore, we find that this population effect results from both a positive effect on fertility and a negative effect on infant and child mortality.

During the past half century the world experienced an unprecedented increase in its population size. In 1960, roughly three billion people inhabited the planet; some 50 years later, in 2011, it was seven billion – with almost one billion people being added in the last decade 2000–10 (UN, 2010). The increase in population size has also been highly unequal across regions. Southern Asia and Africa, where many of the world's poorest people live today, experienced among the highest population growth rates. These regions, inhabited by less than one third of the world's population in 1960, contributed together nearly half of the world's four billion population increase between 1960 and 2010.[1] While from an ecological point of view the tremendous increase in population size could be considered a success – only a thriving ecosystem can generate and sustain a large species – many development practitioners are concerned about environmental, socio-political and economic challenges associated with the large and rapid population expansions of our time. Thus, a natural question to ask is as follows: what has caused the tremendous expansion in population size?

We explore empirically one particular answer to the above question in this study, namely, that the population growth was caused by growth in countries' national income. The hypothesis that the population size is a function of income has deep roots in economics and can be traced back at least to Malthus (1798) who postulated that the increase in population is limited by the means of subsistence. As intuitive as that hypothesis may seem, however, estimating causal effects of variations in national income on population size is complicated by the endogeneity of the former. Textbook macro-economic models predict that changes in countries' population size positively affect output if they lead to increases in the workforce, even though the sign and size of the effect on output *per capita* is more controversial and depends on the details of the underlying model. Moreover, beyond reverse causality going from population size to

[1] Southern Asia's population size was around 600 million in 1960 and over 1.7 billion in 2010; Africa's population size was just a little less than 300 million in 1960, but exceeded one billion in 2010 (UN, 2010).

national income there is the issue of omitted variables. Take, for example, technological change. Leading theories of population growth suggest that a negative correlation between income and population growth (see Figure 1) could be driven by technological change that increases not only incomes but also the opportunity costs of having children. On the other hand, the unconfounded income effect on population size is hypothesised to be positive in this literature.

To zoom in on causal effects of national income on population size we employ an instrumental variables (IV) approach. Our IV approach exploits that the effects of variations in the international oil price on national income differ across countries depending on whether countries are net oil importers or exporters. We construct a country-specific oil price shock variable as the change in the log of the international oil price weighted with countries' sample average net-export shares of oil in GDP. This oil price variable has been used as an instrument for countries' national income in other contexts (Brueckner *et al.*, 2012*a*,*b*; Acemoglu *et al.*, 2013, for an application to US states), but it has not been employed before to study how plausibly exogenous variations in countries' national income affect population size.

For a panel of over 139 countries spanning the period 1960–2007, we first document that the constructed oil price instrument has a positive effect on countries' real GDP *per capita* growth. Consistent with previous literature (Hamilton, 2009; Brueckner *et al.*, 2012*a*,*b*) our estimated first-stage effects are highly statistically significant and impulse response analysis indicates that the identified oil price shocks have permanent effects on the level of GDP *per capita*. We then examine the reduced-form effects on countries'
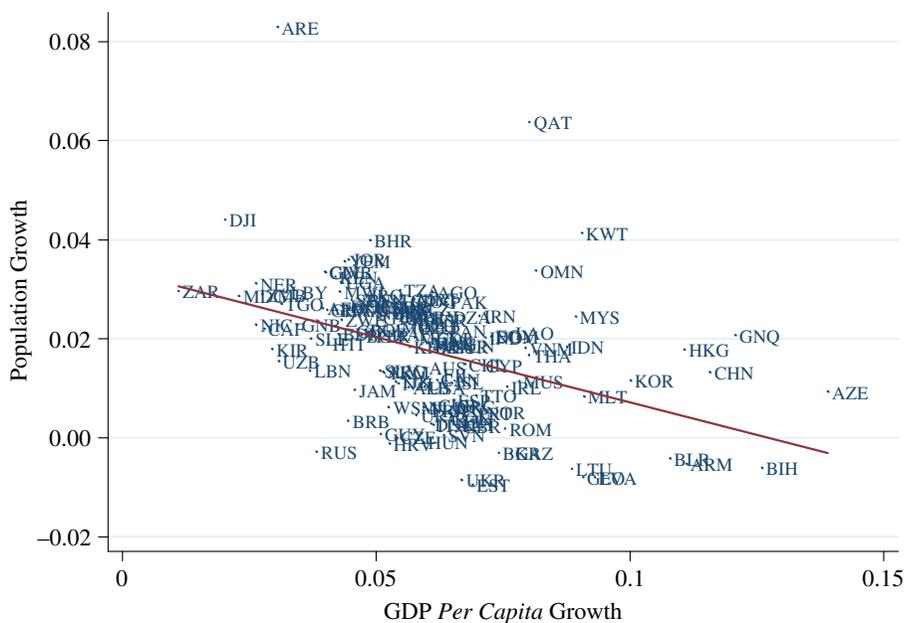
Fig. 1. *GDP Per Capita Growth and Population Growth in the Cross-section of Countries*
Note. Average annual population growth is plotted against average annual GDP *per capita* growth for 139 countries between 1950 and 2010.

population growth. There we find significant positive effects. In contrast to the first-stage effects on GDP *per capita* growth the reduced-form effects become quantitatively large and statistically significant after several years. Thus, the reduced-form analysis indicates significant lagged effects of oil price shocks on countries' population growth.

In the second stage of our instrumental variables analysis we find that countries' GDP *per capita* growth, as instrumented by the oil price variable, has significant positive effects on countries' population growth. Quantitatively, the estimated effects are sizeable. Controlling for country and time fixed effects, we find that a 1 percentage point increase in GDP *per capita* growth over a 10-year period increases countries' population growth rate by around 0.1 percentage points, on average. Consistent with our reduced-form analysis, the effects of GDP *per capita* growth over a five-year period, while positive and significant, are quantitatively smaller: they are about half the size of the effects of GDP *per capita* growth when computed over a 10-year period. Our main finding from the instrumental variables analysis is thus that the effects of increases in countries' national income on population size are positive and significant, but they occur with a lag and tend to cumulate over time.

We document the robustness of the above finding to a variety of sensitivity checks, such as using population weights to account for the greater representativeness of aggregates derived from larger populations; excluding potential outliers (i.e. large positive and negative variations in GDP *per capita* growth, population growth and oil price shocks) from the sample; excluding countries located in the Middle East; excluding countries that are large oil importers; using initial shares of oil net exports in GDP to compute the oil price instrument and using five-year non-overlapping panel data instead of annual data. Consistent with the urban economics literature (Henderson, 2003; Brueckner, 2012), our estimated second-stage effects of GDP *per capita* growth on urban population growth are larger than for rural population growth.

It is noteworthy that our IV estimates are larger than benchmark least squares (LS) estimates. In particular, if we do not control for country fixed effects, least squares estimation yields a negative and significant coefficient on GDP *per capita* growth (in line with the negative cross-country relationship in Figure 1) while the corresponding IV estimate is positive and significant. If we control for country fixed effects, LS estimation yields a positive and significant coefficient on GDP *per capita* growth; however, quantitatively the LS coefficient is smaller than the IV coefficient, more precisely, it is roughly less than half the size of the IV coefficient. One possible interpretation of this difference in LS and IV coefficient is that endogeneity bias is particularly severe, and of negative sign, in the cross-section of countries. Once focus is on within-country variation the sign of the endogeneity bias is still negative but quantitatively smaller.[2]

A key assumption in our instrumental variables estimation is that the reduced-form effects of oil price shocks on population size work through countries' national income. To examine this exclusion restriction, we build on previous literature (Acemoglu *et al.*,

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[2] An alternative interpretation would be that the signal-to-noise ratio is lower when using within-country variation. If that is indeed the case then, in the presence of classical measurement error, the attenuation bias is larger when controlling for country fixed effects. Hence, even in the absence of endogeneity bias, a smaller LS coefficient could arise from classical measurement error. This type of measurement error would attenuate the LS estimate towards zero but not the IV estimate.

2008) and use countries' trade-weighted world income as an additional instrument. This allows us to test whether beyond GDP *per capita* growth the oil price instrument exhibits significant direct effects on countries' population growth. Our main finding is that this is not the case. The conditional effects of the oil price variable on countries' population growth are quantitatively small and statistically insignificant. Moreover, over-identification tests fail to reject the hypothesis that the instruments are uncorrelated with the second-stage residual.

To gain an understanding of what is driving the positive effect of GDP *per capita* growth on population growth, we explore the effects of GDP *per capita* growth on fertility rates, mortality rates and measures of countries' demographic composition. Using the oil price variable as an instrument, we find that GDP *per capita* growth has a significant positive effect on within-country changes in fertility rates and a significant negative within-country effect on changes in infant as well as child mortality rates. In terms of the effects on demographic composition, higher GDP *per capita* growth has a significant positive effect on within-country changes in the share of population aged 0–14 and child dependency ratios but a significant negative effect on within-country changes in the share of population aged 15–64 (i.e. the working-age population). We do not find significant effects on the share of the population aged 64 and above or on the old age dependency ratio. These results suggest that the positive effects of national income on population size are likely to arise primarily from a positive effect on net fertility (i.e. the number of children surviving the first years of life) rather than a decline in old-age mortality.

The remainder of our study is organised as follows. In Section 1 we discuss related literature. This is followed by a discussion of our estimation strategy as well as description of the data. Section 3 presents and discusses the main empirical results. Section 4 concludes. An online Appendix B contains further results.

1. Related Literature

Our study presents the first empirical attempt to provide within-country estimates of the causal effect of growth in countries' national income on population growth based on using an instrumental variables approach. This provides an important contribution to the voluminous literature on income and population size which dates back at least to the 18th century. By that time, as most famously described by Malthus (1798), income gains directly translated into population growth keeping income *per capita* constant and increasing only population density.[3] During the Industrial Revolution, however, population dynamics changed from the Malthusian model to the Modern Growth Regime which is characterised by economic growth coupled with declining fertility (Galor and Weil, 2000).[4] Over the past century, income *per capita* and population growth have been negatively correlated (Weil, 2012; Figure 1). As children are considered a normal good in most modern discussions of fertility (Lee, 1997; Black

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[3] As mentioned in Galor and Weil (2000), Adam Smith (1776, p. 63) observed: 'The most decisive mark of the prosperity of any country is the increase in the number of its inhabitants'.
[4] In a recent study, Moeller and Sharp (2014) suggest that England might have started this transition as early as two centuries preceding the Industrial Revolution.

et al., 2013) and life expectancy is higher in richer countries (Cutler *et al.*, 2006), this is a puzzling relationship. Leading theories explaining this relationship suggest that technical progress underlying income growth since the Industrial Revolution increased the direct and opportunity costs of fertility (for a comprehensive review see Jones *et al.*, 2010).[5] These costs outweigh the positive income effects of economic growth, such that richer countries end up with lower fertility rates. In other words, technological progress can be interpreted as a confounder of the income–fertility relationship that affects incomes and fertility in different directions.[6] In turn, income increases that are not generated by technological progress should be associated with higher not with lower fertility. We directly test this hypothesis at the macro-economic level, thus taking into account general equilibrium effects. Our instrument, the interaction of a country's average net-export share of oil in GDP with changes in world oil prices, identifies windfall GDP gains that are unlikely to be affected by country-specific technological changes. Our study is the first attempt to identify exogenous income shocks in cross-country panel data to estimate unconfounded effects of income changes on population growth.

Few studies have so far explored unconfounded income effects on fertility. Lee (1997) reviews evidence on the wage–fertility relationship in pre-industrial economies, arguing that in these economies wage changes are less likely to be confounded with institutional and technological progress than in developed countries. He reports positive income elasticities of fertility for most countries. Black *et al.* (2013) analyse a homogenous sample of US women in the mid-1970s, finding that fertility is positively correlated with husbands' income. These findings are consistent with children being 'normal goods'. Our evidence of positive effects of national income growth on fertility supports this notion.

Our study further contributes to the literature on the effects of income on health. The effects of health on economic growth are subject to a broad literature – Weil (2007) and Acemoglu and Johnson (2007) are two central contributions and Deaton (2006) offers an insightful review – but fewer studies have investigated effects running the opposite direction, from income to health. Pritchett and Summers (1996) use countries' terms of trade, investment ratios, black market premia and price level distortions as instruments for *per capita* GDP and estimate income elasticities of infant and child mortality between -0.2 and -0.4. While Pritchett and Summers's (1996) instruments are rather weak and exclusion restrictions could have been violated (Deaton, 2006), their estimates are close to the elasticities that we find.

Cotet and Tsui (2009) investigate whether oil discoveries affect countries' population size and health outcomes. They compare changes in these outcomes in countries

[5] Becker (1960) hypothesises that technological progress increases the returns to investments into children and therefore induces parents to substitute quality for quantity. Galor and Weil (1996) argue that institutional change and technological progress increased the female-to-male wage ratio and thereby the opportunity costs of fertility. Caldwell (1976) points out that lower net flows from children to parents in more developed countries may also increase the direct costs of having children. Herzer *et al.* (2012) employ panel co-integration techniques to show that fertility declines over the past century were driven by technological change (and associated income increases) and not merely a consequence of falling mortality rates.

[6] Murtin (2013) empirically identifies education (driven by technological progress) as one confounding factor, showing that the correlation of income and fertility weakens once education is controlled for.

with and without major oil discoveries around the 1960s. Interestingly, they find that countries with oil discoveries experienced stronger population growth and lower child mortality. The effects on GDP growth are not significantly different from zero in the decade following oil discoveries but positive in the long run.

Cotet and Tsui's empirical strategy differs from ours in a number of important aspects. First, as Cotet and Tsui (2009) note, unobservable factors that might affect both a country's oil discoveries and subsequent growth make a causal interpretation of their findings difficult. Haber and Menaldo (2011) and Haber *et al.* (2003) make a similar argument, pointing out that oil discoveries are correlated with predetermined country characteristics. Cotet and Tsui also present first-difference specifications in which they regress income, population and health changes on changes in *per capita* oil rents. However, while changes in oil rents due to changes in world oil prices are plausibly exogenous, changes in a country's oil production costs and volumes might be driven by time-varying country-specific factors that also affect income and population growth. The strategy in our study is to exploit time-series variation in global oil prices interacted with countries' average GDP shares of net oil exports. As the latter is time invariant by construction, our instrument is not confounded by potentially endogenous time-series variations in countries' oil production.

A second key advantage of our instrumental variables approach is that it does not confound effects of GDP *per capita* growth on population growth with technological progress. Country-specific technological progress could imply both increases in oil production (discoveries) and population growth. Because the time-series variation in our instrument is exclusively driven by the time-series variation in the international oil price, our IV estimation approach is immune to the confounding effects of technological progress.

Two recent studies by Maccini and Yang (2009) and Miller and Urdinola (2010) carefully identify transitory macro-economic shocks and analyse their effects on infant mortality and child health. Maccini and Yang (2009) show in Indonesian data that less rainfall at the year and location of birth leads to worse health outcomes and lower socio-economic status for women but not for men. They interpret these findings as evidence that negative income shocks around birth adversely affect those household members that are particularly vulnerable. Miller and Urdinola (2010), on the other hand, find that world coffee prices at the year of birth correlate positively with subsequent infant mortality among coffee farmers in Colombia. This negative income effect on child health is explained by a positive effect of coffee prices on the opportunity costs of child care. Lower coffee prices are associated with fewer hours worked, in particular for women (the primary caregivers of children), which decreases the costs of time investments in child health. The contrary effects found in these two studies, both well-identified and credible, point out that different sources of income shocks may translate differently into child health, depending on whether the substitution or the income effect dominates.

2. Estimation Strategy

Our econometric model relates the change in the log of countries' population size to the change in the log of GDP *per capita*:

$$\Delta\ln(Pop_{it}) = a_i + b_t + \theta\Delta\ln(GDP_{P \cdot c \cdot_{it}}) + e_{it}, \tag{1}$$

where a_i are country fixed effects and b_t are year fixed effects.

There are several important issues in the estimation of θ in (1). One is endogeneity bias. Endogeneity bias could arise due to within-country changes in population size having an effect on (contemporaneous) GDP *per capita* growth. *A priori* it is not clear what the direction of this bias is. With decreasing returns to scale in labour, as is the case in neoclassical models, the bias is negative; however, if there are increasing returns to scale in labour, say, due to a large population generating more ideas (Jones, 2005), then the reverse causality bias could be positive. Endogeneity bias could also arise due to omitted variables that are varying at the within-country level. These would have to be variables that

  (*i*) affect GDP *per capita* growth; and
  (*ii*) affect population growth beyond GDP *per capita* growth (i.e. are part of the error term, *e*).

An example is growth spurring technological innovations that increase the opportunity costs of fertility, say, through higher returns to female labour supply or child quality (Becker, 1960; Galor and Weil, 1996). This would imply a negative correlation of (innovation-induced) GDP *per capita* growth and population growth. Likewise, medical or work place safety innovations might lead to higher productivity while lowering mortality and thereby increasing population size, for example, the introduction of new laser technologies and other computerised equipment that reduces the margin of error in surgeries. Also the introduction of new drugs or disease prevention measures can either prevent or treat diseases that in turn enable an increase in work effort and may also lead to longer life expectancy. Such technological innovations which increase productivity are likely to have very large direct effects on population size, in particular, through life expectancy.

Another important issue is that θ is likely to differ depending on the source of growth in national income. One natural distinction here is between transitory and permanent income shocks. Inter-temporally optimal fertility decisions and public good provision should respond more strongly to permanent shocks than to temporary shocks. Hence, it is likely that θ is larger for variations in GDP *per capita* that are of permanent nature.

To address the above issues we use an instrumental variables approach. Our instrumental variable is the change in the international oil price multiplied with countries' sample average GDP shares of net oil exports. This instrument captures variations in countries' national income that arise due to plausibly exogenous variations in its terms of trade. Year-to-year variations in the international oil price are highly persistent (Hamilton, 2009 or Brueckner *et al.*, 2012*a,b*). Hence, our instrumental estimates should be interpreted as capturing the effects of permanent variations in countries' national income.

We estimate the effects of growth in national income on population size based on annual data. This allows us to examine both short-run and longer run effects of income on population size. In (1) θ captures the short-run (i.e. contemporaneous) effect of income growth on population growth. It is possible, however, that the effects

of oil price–induced income growth on population growth build up over time. To examine dynamic effects, we will present estimates from a reduced-form model that includes the year t oil price variable as well as lags of this variable up to 10 years. That is, we estimate:

$$\Delta \ln(Pop_{it}) = \alpha_i + \beta_t + \Sigma \gamma_r OilShock_{it-r} + \varepsilon_{it}. \tag{2}$$

The coefficients γ_r capture the dynamic effects of variations in the oil price variable on countries' population growth.

The data on population growth, fertility and mortality are drawn from the World Development Indicators (WDI, 2011). Real purchasing power parity (PPP) GDP *per capita* data are taken from the Penn World Table version 7.1 (Heston *et al.*, 2012). The oil price instrument is constructed using oil import and export data from the NBER-UN Comtrade (Feenstra *et al.*, 2004) merged with oil price data from the UNCTAD Commodity Price Statistics (UNCTAD, 2011). Trade-weighted world income, as an additional income instrument, is taken from Acemoglu *et al.* (2008). For a description of the variables used in the estimation see Table 1. Summary statistics are provided in Table 2.[7]

3. Results

3.1. *Effects of Income Growth on Population Growth*

We begin our analysis by estimating the reduced-form effects that the oil price instrument has on population growth based on (2). The control variables are country and year fixed effects; standard errors are Huber robust and clustered at the country level. Figure 2 plots the coefficients with their 95% confidence bands. The main finding is that the coefficients on all lags from $t-0$ to $t-10$ are positive; however, only the lags from $t-5$ to $t-10$ are statistically significant. This suggests that the oil price variable's effect on population growth arises with a lag, i.e. it takes time for the effect on population growth to materialise. Summing up the coefficients on lags $t-0$ to $t-10$ yields a cumulative effect of 0.72 with a standard error of 0.38. This cumulative effect is significant at the 10% significance level (p = 0.06).

We repeat the exercise for GDP *per capita* growth. The coefficients and their 95% confidence bands are plotted in Figure 3. The main finding is that only the year t to $t-2$ coefficients are positive and significant. The other coefficients on further lags are insignificant and quantitatively small. Summing up the coefficients on lag $t-0$ to $t-10$ yields a cumulative effect of 2.43 with a standard error of 0.76. This effect is significant at the 1% significance level (p = 0.002). As the dependent variable is GDP *per capita* growth and the oil variable is defined as the change in the log of the international oil price weighted with countries' average (and thus time invariant) net-export shares of oil in GDP, the estimates suggest that variations in the oil price have permanent effects on the level of GDP *per capita*, which is consistent with previous research (Hamilton, 2009 and Brueckner *et al.*, 2012*a,b*).

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[7] Online Appendix Table B1 provides a list of the countries in the sample.

Table 1

Description of Variables

Variable	Description	Source
Population growth	Population growth (annual %) is the exponential rate of growth of the total population in a country between year $t-1$ to t. Urban (rural) population growth refers to population growth in urban (rural) areas	WDI (2011)
Fertility rate	Total fertility rate represents the number of children that would be born to a woman if she were to live to the end of her childbearing years and bear children in accordance with current age-specific fertility rates	WDI (2011)
Infant mortality	Infant mortality rate is the number of infants dying before reaching one year of age, per 1,000 live births in a given year	WDI (2011)
Under-five mortality	Under-five mortality rate is the probability per 1,000 that a newborn baby will die before reaching age five, if subject to current age-specific mortality rates	WDI (2011)
Share of the population aged 0–14, 15–64, 65+	The population between the ages of 0–14, 15–64, 65+, respectively, as a fraction of the total population	WDI (2011)
Child dependency ratio	The ratio of child dependents (people between 0 and 14) to the working-age population (those ages 15–64)	WDI (2011)
Old age dependency ratio	Age dependency ratio, old, is the ratio of older dependents (people older than 64) to the working-age population (those ages 15–64)	WDI (2011)
Female-to-male population ratio	The population ratio of females to males	WDI (2011)
Female labour force participation rate	The proportion of the female population ages 15 and older that is economically active	WDI (2011)
Ratio female-to-male labour force participation	Female labour force participation divided by male labour force participation	WDI (2011)
Ratio female-to-male employment	Female employment divided by male employment	WDI (2011)
Immigration	Natural logarithm of immigration stock	WDI (2011)
GDP p.c. growth	PPP GDP *per capita* growth	Heston *et al.* (2012)
TFP growth	Total factor productivity growth	Feenstra *et al.* (2013)
Oil price instrument	Change in the international oil price multiplied by countries' average GDP share of net exports of oil	Feenstra *et al.* (2004) and UNCTAD (2011)
Trade-weighted world income	Sum of the change in trading partners' GDP multiplied by average bilateral trade shares	Acemoglu *et al.* (2008)

We now turn to our baseline two-stage least squares estimates. The findings from the reduced-form analysis indicated that oil price–driven income shocks have positive effects on population growth that accumulate over time. Hence, we use in our baseline two-stage least squares estimation the change in the log of GDP *per capita* over 10 years, i.e. between $t-0$ and $t-10$. The oil price instrument is then constructed as the change in the log of the international oil price between $t-0$ and $t-10$ multiplied with countries' average net-export shares of oil in GDP.

We report our baseline two-stage least squares estimates in panel (*a*) of Table 3. In panel (*b*) of Table 3 we report for comparison the corresponding least squares estimates. In column (1) we report pooled panel estimates without controlling for

Table 2

Summary Statistics of Population Variables

Variable	Mean	SD
Population growth	0.02	0.01
Urban population growth	0.03	0.02
Rural population growth	0.01	0.03
Fertility rate	4.11	1.99
Infant mortality rate	57.01	44.62
Under-five years mortality rate	87.24	78.41
Female labour force participation rate	0.51	0.18
Ratio female-to-male labour force	0.66	0.22
Share of population age 0–14	0.36	0.10
Share of population age 15–64	0.58	0.07
Share of population age 65+	0.06	0.04
Child dependency ratio	0.64	0.23
Old age dependency ratio	0.10	0.06
Female-to-male ratio	1.01	0.06
Ratio female-to-male employment	0.66	0.22
Immigration	12.19	1.76
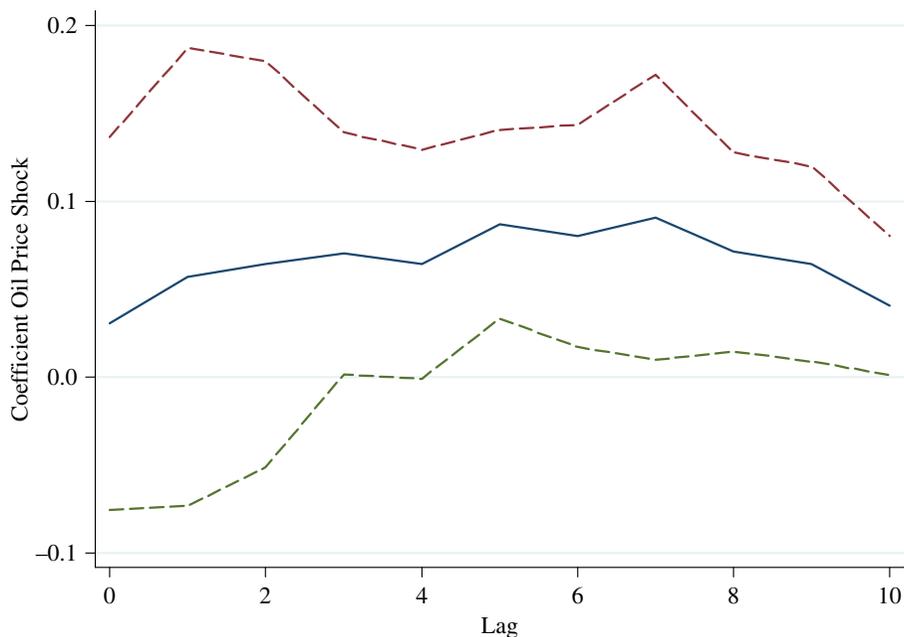
Fig. 2. *Dynamic Effects of Oil Price Instrument on Population Growth*
Notes. Dashed lines are 95% confidence bands. The Figure is generated from a panel regression with country and year fixed effects; Huber robust standard errors are clustered at the country level. The dependent variable in the panel regression is population growth.

country or year fixed effects. In this case the coefficient on GDP *per capita* growth is 0.35 and has a SD of 0.15. In column (2) we add year fixed effects. The year fixed effects are jointly significant at the 1% significance level. Adding the year fixed effects to the right-hand side of the regression implies that our estimates are identified by
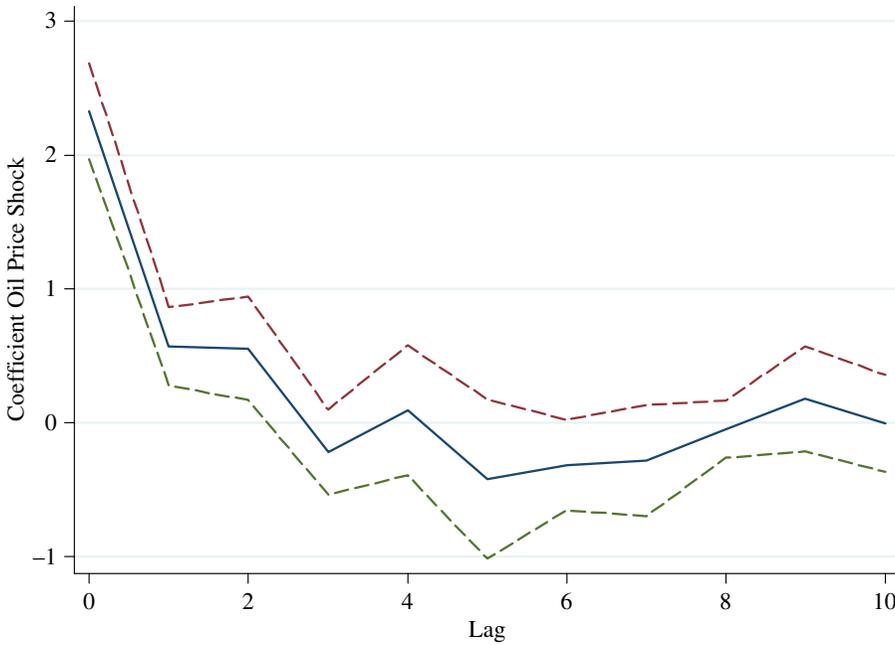
Fig. 3. *Dynamic Effects of Oil Price Instrument on GDP p.c. Growth*

Notes. Dashed lines are 95% confidence bands. The Figure is generated from a panel regression with country and year fixed effects; Huber robust standard errors are clustered at the country level. The dependent variable in the panel regression is GDP *per capita* growth.

Table 3

Effects of Income Growth on Population Growth (Baseline Estimates)

Population growth	(1)	(2)	(3)	(4)	(5) Urban	(6) Rural
Panel (*a*): 2SLS						
GDP p.c. growth	0.35**	0.45**	0.11*	0.14*	0.16*	0.07
(10-year average)	(0.15)	(0.19)	(0.06)	(0.07)	(0.09)	(0.11)
Kleibergen Paap F-statistic	25.73	26.91	56.18	53.63	53.63	53.63
First-stage						
Oil price instrument	0.25***	0.20***	0.38***	0.28***	0.28***	0.28***
(10-year average)	(0.05)	(0.04)	(0.05)	(0.04)	(0.04)	(0.04)
Panel (*b*): LS						
GDP p.c. growth	−0.02	−0.06***	0.06***	0.04***	0.02	0.03*
(10-year Average)	(0.01)	(0.02)	(0.01)	(0.01)	(0.03)	(0.02)
Time FE	No	Yes	No	Yes	Yes	Yes
Country FE	No	No	Yes	Yes	Yes	Yes
Observations	4,428	4,428	4,428	4,428	4,428	4,428

Notes. The method of estimation in panel (*a*) is two-stage least squares; panel (*b*) least squares. The dependent variable in columns (1)–(4) is total population growth; in column (5) urban population growth; column (6) rural population growth. The instrumental variable in panel (*a*) is the change in the international oil price between year t and $t-10$ multiplied by countries' average GDP share of net oil exports. Huber robust standard errors (shown in parentheses) are clustered at the country level. *Significantly different from zero at 10% significance, **5% significance, ***1% significance.

deviations from global (non-linear) trends. In other words, global economic conditions that have common effects on countries' economic growth and population growth are partialled out from the residual. In column (3) we substitute the year fixed effects for country fixed effects, and in column (4) we include both country and year fixed effects in the regression model. Including country fixed effects as right-hand-side control variables implies that our estimates are identified by deviations in economic growth and population growth from countries' 1960–2007 mean. The control for country fixed effects leads to a smaller coefficient on GDP *per capita* growth: the coefficient on GDP *per capita* growth is now around 0.1. But the estimated effect is still significant at the 10% level (the p-value is 0.06 in column (3) and 0.07 in column (4)). One possible interpretation of the smaller coefficient on GDP *per capita* growth in the regressions that control for country fixed effects is that the long-run effects of GDP *per capita* growth on population growth are larger than the medium-run effects. Quantitatively, the coefficient of 0.1 suggests that a 1% increase in GDP *per capita* over a 10-year period increases the population size by around 0.1%.

A comparison of the least squares estimates, reported in panel (*b*) of Table 3, with the instrumental variables estimates shows that the former are significantly smaller. This is especially so in the regressions that do not control for country fixed effects (columns 1 and 2). In these regressions, the least squares coefficients on GDP *per capita* growth are negative and, once year fixed effects are controlled for, the negative coefficient is significantly different from zero at the 1% level. On the other hand, in columns (3) and (4) that control for country fixed effects the least squares coefficients on GDP *per capita* growth are positive and significantly different from zero at the conventional significance levels. However, quantitatively they are less than half the size of the corresponding IV coefficients. One interpretation of this difference between IV and LS coefficients is that in the cross-section of countries the (negative) endogeneity bias on the least squares estimates is particularly severe.

The existing panel data on urban and rural population growth also enable us to explore whether the effects of oil price–driven income growth are particularly large in urban or rural areas. A common view in the urban economics literature (Henderson, 2003; Brueckner, 2012) is that economic growth is associated with a shift of the population from rural areas to cities. Consistent with this view, the instrumental variables estimates in column (5), where the dependent variable is urban population growth, yield a larger coefficient on GDP *per capita* growth than in column (6), where the dependent variable is rural population growth. In particular, the coefficient that captures the effects of oil price-driven income growth on urban population growth is 0.16, whereas the effect on rural population growth is only 0.07.

The regressions reported in Table 3 weight each country-year observation equally which is common practice in macro-economic cross-country regressions. In Table 4 we repeat the baseline regressions weighting observations by the countries' average population size. Population sizes in our sample vary by up to four orders of magnitude across countries. In the context of population growth, the relevant mechanisms, such as fertility decisions and infant health operate at the level of the individual household.

Table 4

Effects of Income Growth on Population Growth (Population-weighted Estimates)

Population growth	(1) 2SLS Total	(2) 2SLS Urban	(3) 2SLS Rural	(4) LS Total	(5) LS Urban	(6) LS Rural
GDP p.c. growth (10-year average)	0.06*** (0.02)	0.08** (0.04)	0.07** (0.03)	0.01 (0.02)	0.10* (0.07)	−0.05 (0.05)
Kleibergen Paap F-statistic	17.98	17.52	19.21			
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4,428	4,428	4,428	4,428	4,428	4,428

Notes. The method of estimation in columns (1)–(3) is population-weighted two-stage least squares; columns (4)–(6) population-weighted least squares. The instrumental variable in columns (1)–(3) is the change in the international oil price between year t and $t-10$ multiplied by countries' average GDP share of net oil exports. The dependent variable in columns (1) and (4) is total population growth; columns (2) and (5) urban population growth; columns (3) and (6) rural population growth. Huber robust standard errors (shown in parentheses) are clustered at the country level. *Significantly different from zero at 10% significance, **5% significance, ***1% significance.

Observations representative for very large countries like India with one billion inhabitants are likely to tell us more about the income effects on the world's average household than observations from very small countries like Belize which has a population of less than 0.0002 billion. This is particularly relevant as we are interested in the determinants of world population growth rather than the (unweighted) average population growth across countries. We therefore report estimates that use population weights in all tables that follow.

The main result from Table 4 is that the estimated effects in the population-weighted 2SLS regressions in the total and the urban samples are about half the size of the unweighted estimates while standard errors are decreased by two thirds. The second-stage coefficient in column (1) of Table 4 is 0.06. The coefficient is significant at the 1% significance level and suggests that a 1 percentage point increase in GDP *per capita* growth over a 10-year period increases population growth by 0.06 percentage points. The difference between the urban and the rural estimates in columns (2) and (3) is still positive though smaller compared to the unweighted regressions in Table 3.

In Table 5, we examine whether our instrumental variables estimates are driven exclusively by the countries in the Middle East. Over the 1960–2007 period, countries in the Middle East have experienced tremendous population growth, in excess of 3% per annum on average. And many of these economies are highly dependent on oil exports. In column (1) of Table 5, we report IV estimates for the countries in the Middle East. In column (2), we report the corresponding least squares estimates. The main finding is that the coefficient on GDP *per capita* growth in the sample of Middle Eastern countries is positive and significant. In the sample that excludes the Middle Eastern countries, the IV coefficient on GDP *per capita* is smaller but also positive and significant. However, the least squares coefficient is insignificant for the sample that excludes the Middle Eastern countries; see columns (3) and (4).

Table 5

Effects of Income Growth on Population Growth (are the Middle Eastern countries different?)

Population growth	(1) 2SLS Middle East	(2) LS Middle East	(3) 2SLS Excl. Middle East	(4) LS Excl. Middle East
GDP p.c. growth (10-year average)	0.09*	0.02**	0.04*	−0.00
	(0.05)	(0.01)	(0.02)	(0.02)
Kleibergen Paap F-statistic	16.75		23.02	
Time FE	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes
Observations	385	385	4,043	4,043

Notes. The method of estimation in columns (1) and (3) is population-weighted two-stage least squares; columns (2) and (4) weighted least squares. The instrumental variable in columns (1) and (3) is the change in the international oil price between year t and $t-10$ multiplied by countries' average GDP share of net oil exports. The dependent variable is total population growth. Columns (1) and (2) report estimates for the sample of Middle Eastern countries. These are as follows: Bahrain, Cyprus, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, Turkey, United Arab Emirates and Yemen. Columns (3) and (4) report estimates for the sample that excludes countries from the Middle East. *Significantly different from zero at 10% significance, **5% significance, ***1% significance.

3.2. *Discussion of Instrument Quality*

In this subsection, we discuss the quality of our instrumental variables estimates. We begin by discussing instrument relevance, i.e. the quality of the first-stage relationship between the oil price instrument and GDP *per capita* growth. This is followed by a discussion of instrument validity, i.e. whether the oil price instrument is plausibly exogenous and fulfils the exclusion restriction.

In terms of the instrument's relevance, the Kleibergen Paap F-statistic is always in excess of 10. Hence, according to Staiger and Stock (1997) we can reject the null of weak instrument bias. Economically, the first-stage coefficient on the oil price variable is also sensible. The positive coefficient implies that increases in the international oil price lead to increases in the national income of countries that are net exporters of oil (the terms of trade effect). Quantitatively, the estimated first-stage relationship suggests that a 1% increase in the oil price instrument increases GDP *per capita* growth by around 0.3%.

An important identifying assumption in our instrumental variables estimation is that country-specific shocks do not affect the international oil price. To be clear, the assumption is not that the international oil price is unaffected by world-wide supply and demand. In the panel regressions, the endogenous response of the international oil price to world-wide demand and supply is captured by the year fixed effects. Still, demand-side explanations of variations in the oil price have been related to shocks emanating in a few large countries, e.g. changes in US monetary policy and the rapid growth of China (Hamilton, 2013). We show in column (1) of Appendix Table A1 that excluding the handful of large oil-importing countries (defined as countries that imported on average >3% of world oil imports) leaves the main finding of our instrumental variables regressions unaffected.[8]

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[8] The excluded countries are China, France, Japan, the Netherlands, South Korea, US and the UK.

On the supply side, the underlying assumption is that the amount of oil extracted in an oil-producing country is independent of the country's population growth. A concern may be that geopolitical events (wars) in the Middle East have an effect on the international oil price. Existing evidence suggests, however, that world-wide supply of oil was not significantly affected by such events as oil-producing countries with excess capacity found it lucrative to increase supply (Hamilton, 2013).[9] We furthermore note that as documented in Table 5 the instrumental variables estimates showed a significant positive effect of income on population growth in the sample that excludes countries located in the Middle East.

In column (2) of Appendix Table A1, we document that our instrumental variables estimates are robust to using initial shares of net oil exports in GDP. So far we used countries' period average shares of net oil exports in GDP to construct the oil price instrument. Period average net-export shares have the advantage of capturing countries' net exports of oil more appropriately over the sample period. However, one might be concerned that the period average net-export shares of oil are endogenous. *A priori*, this bias should be small as any feedback effects are discounted by a factor of $1/T$. Indeed, the IV estimates in column (2) of Appendix Table A1 that use the 1970 net oil export GDP shares to construct the oil price instrument are very similar to our baseline estimates which use the period average net-export shares.[10]

Examining the effect of national income on population growth requires not only using an exogenous source of variation in GDP; it also requires using a source of variation that is unrelated to technological progress, see the discussion in Section 1. An important identifying assumption in our instrumental variables estimation is thus that the oil price instrument has no significant effect on technological progress. To better evaluate whether this is a plausible assumption, it is useful to recall that:

(*i*) the oil price instrument is constructed as the interaction between the change in the log of the international oil price over a 10-year period and countries' average net-exports shares of oil in GDP;

(*ii*) the panel regressions control for year fixed effects (that capture among other factors world-wide technological progress).

The identifying assumption is hence that variations in the international oil price have no systematic differential effect on the rate of technological progress across countries as a function of countries' oil net-export GDP shares. This is a weaker assumption than changes in the international oil price having no effect on the path of technological progress (in particular, if one views technological progress as being driven by an expansion of the world technology frontier). Increases in the international oil price make it more costly to use oil as an input factor in production. As a consequence, an increase in the international price of oil may spur technological innovation that leads to more efficient energy use in the production process (Hassler *et al.*, 2012). If the incentive for technological innovation is common across countries (i.e. both oil-

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[9] Hamilton (2013) also makes the point that many studies have failed to find statistical evidence for OPEC behaving as a cartel.

[10] The estimates in column (2) of Appendix Table A1 use the 1970 oil net-export GDP shares and focus on the post-1970 period because data on oil exports and imports are very sparse for the pre-1970 period.

exporting and oil-importing countries benefit by increasing the efficiency of oil use in the production process), then our oil price instrument does not have an effect on country-specific technological progress.

Table 6 presents estimates of the effect that the oil price instrument has on total factor productivity (TFP) growth.[11] To facilitate comparison of these estimates to the impact that the oil price instrument has on GDP *per capita* growth, Table 6 is structured in exactly the same way as the first four columns of Table 3. The main finding from Table 6 is that the effect of the oil price instrument on TFP growth is insignificant and this is true regardless of whether we control for country or time fixed effects. Quantitatively, the estimated effect is also quite small. For example, with country and time fixed effects included in the model, as is done in all the other estimates reported in the study, the estimated coefficient on the oil price instrument is −0.010. This estimated effect implies that a 1 SD increase in the oil price instrument leads to a (statistically insignificant) decrease in TFP growth of around 0.009 standard deviations. For comparison, the estimated effect on GDP *per capita* growth, reported in column (4) of Table 3, is around 0.36 SD. These findings underscore the assumption that the oil price instrument is unrelated to country-specific technological progress.

The exclusion restriction in our instrumental variables regressions is that the oil price instrument should only affect countries' population growth through growth in national income. One concern may be that the instrument has a direct effect on population growth through the cost of having children. The review of the literature provided in Jones *et al.* (2010) suggests that changes in the female wage rate affect the cost of having children and hence population growth. To check whether this force is present in our data set we would ideally like to regress female wages on the oil price instrument or alternatively control for female wages. Unfortunately, this is not feasible

Table 6

Effects of Oil Price Instrument on Total Factor Productivity (TFP) Growth

TFP growth	(1) LS	(2) LS	(3) LS	(4) LS
Oil price instrument (10-year average)	−0.107	−0.107	−0.014	−0.010
	(0.142)	(0.126)	(0.122)	(0.101)
Time FE	No	Yes	No	Yes
Country FE	No	No	Yes	Yes
Observations	3,135	3,135	3,135	3,135

Notes. The method of estimation is population-weighted least squares. The dependent variable is TFP growth. Huber robust standard errors (shown in parentheses) are clustered at the country level. *Significantly different from zero at 10% significance, **5% significance, ***1% significance.

[11] The TFP data are from PWT 8.0 (Feenstra *et al.*, 2013). Specifically, we use the *rtfp* series that measures TFP at constant prices. In the PWT 8.0, the TFP series are constructed by deflating real GDP data by the Törnqvist quantity index of factor endowments. This index of factor endowments uses data on the country-specific capital stock, labour input, human capital and the labour income share. A detailed explanation of how the TFP data are constructed as well as a discussion on the underlying data on the various factor endowments is provided in Feenstra *et al.* (2013) and Inklaar and Timmer (2013).

due to sparseness of data on female wages. There are, however, panel data for female labour force participation for a large cross-section of countries and time span from the World Development Indicators. Using these data, we show in column (3) of Appendix Table A1 that the effect of the oil price instrument on the female labour force participation rate is insignificant.[12]

We have also explored whether the oil price instrument has significant effects on population growth beyond its effect on national income growth. In previous research, Acemoglu *et al.* (2008) introduced countries' trade-weighted world income as an instrument for national income. Building on this work, and using five-year non-overlapping panels as in Acemoglu *et al.* (2008), we present, in Table 7, instrumental variables estimates that use countries' trade-weighted world income as an additional instrument. We first show in column (1) of Table 7 that conditional on GDP *per capita* growth the oil price instrument has an insignificant effect on population growth. Importantly, in this regression that uses the change in the log of trade-weighted world

Table 7

Effects of Income Growth on Population Growth (Examination of Exclusion Restriction, Five-year Non-overlapping Panel)

Population growth	(1) 2SLS	(2) LS	(3) 2SLS	(4) LS
GDP p.c. Growth, t	0.21** (0.10)			
Oil price instrument, t	−0.39 (0.27)	0.65*** (0.24)		
GDP p.c. growth, $t-1$			0.18** (0.09)	
Oil price instrument, $t-1$			−0.25 (0.25)	0.43*** (0.16)
Kleibergen Paap F-statistic	35.61		35.61	
First stage for GDP p.c. growth				
Oil price instrument, t	2.18*** (0.47)			
Trade-weighted world income growth instrument, t	0.27*** (0.05)			
Oil price instrument, $t-1$			2.18*** (0.47)	
Trade-weighted world income growth instrument, $t-1$			0.27*** (0.05)	
Time FE	Yes	Yes	Yes	Yes
Country FE	No	No	No	No
Observations	738	946	738	946

Notes. The method of estimation in columns (1) and (3) is population-weighted two-stage least squares; columns (2) and (4) is population-weighted least squares. The dependent variable is total population growth in a five-year non-overlapping panel. Huber robust standard errors (shown in parentheses) are clustered at the country level. *Significantly different from zero at 10% significance, **5% significance, ***1% significance.

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[12] There are also no significant effects of the oil price instrument on the ratio of female-to-male labour force participation or female-to-male employment, see columns (4) and (5) of Appendix Table A1.

income as an excluded instrument for GDP *per capita* growth, the second-stage coefficient continues to be positive and significant at the conventional significance levels. On the other hand, unconditional on GDP *per capita* growth, the oil price instrument has a significant positive reduced-form effect on population growth, as it should have given its significant positive first-stage effect on GDP *per capita* growth. In columns (3) and (4) we repeat the exercise using lagged GDP *per capita* growth (i.e. between year $t-6$ and $t-10$) and find similar results.

3.3. *Effects on Fertility, Mortality and Demographic Composition*

Our instrumental variables analysis indicates a robust positive effect of income growth on population growth. This finding is in contrast with the negative income–population relationship that is observed in the cross-section of countries (Figure 1). The negative relationship has been explained with technological progress acting as a confounding factor which increases both income as well as the opportunity costs of fertility. The negative effects on fertility outweigh the positive income effects on survival and on fertility summing up to a decline in population growth. This implies that in the absence of such a confounding factor, the observed effect of income on both survival and fertility should be positive. As argued above, our oil price instrument is unlikely to be confounded by technological changes. Therefore, it is of interest to examine the effects of instrumented income growth on changes in fertility and mortality rates.

Column (1) of Table 8 presents instrumental variables estimates of the effects that oil price–driven income growth has on within-country changes in fertility rates. The second-stage coefficient is 1.2 and has a standard error of 0.5. Hence, we can reject the null hypothesis that oil price-driven income growth has no significant effect on changes in countries' fertility rates at the 5% significance level. Quantitatively, the coefficient of 1.2 implies that on average a 10 percentage point increase in countries' national income growth over a 10-year period leads to an increase in the change in the

Table 8

Effects of Income Growth on Fertility and Mortality

	ΔFertility rate	ΔInfant mortality	ΔUnder-five mortality
	(1) 2SLS	(2) 2SLS	(3) 2SLS
GDP p.c. growth (10-year average)	1.23**	−14.32***	−27.06***
	(0.47)	(4.31)	(8.20)
Kleibergen Paap F-statistic	18.01	17.91	17.91
Time FE	Yes	Yes	Yes
Country FE	Yes	Yes	Yes
Observations	4,450	4,401	4,401

Notes. The method of estimation is population-weighted two-stage least squares. The dependent variable in column (1) is the change in the fertility rate; column (2) the change in the infant mortality rate; column (3) the change in the under-five years mortality rate. Huber robust standard errors (shown in parentheses) are clustered at the country level. The instrumental variable is the change in the international oil price between year t and $t-10$ multiplied by countries' average GDP share of net oil exports. *Significantly different from zero at 10% significance, **5% significance, ***1% significance.

fertility rate by over 0.1 units. Thus, very roughly, a doubling of national income leads to one additional child born per woman. These results are in line with children being a 'normal good' (Lee, 1997; Black *et al.*, 2013).

Our instrumental variables estimates also show that increases in national income are associated with lower infant mortality rates. The second-stage coefficient on income growth in column (2) of Table 8 is −14.3 and has a SE of 4.3. As infant mortality rates are calculated as the number of infants dying before reaching one year of age, per 1,000 live births in a given year, the coefficient of −14.3 should be interpreted as a 20 percentage points increase in national income growth leading to a reduction in the change in infant mortality of nearly three infants per 1,000 live births. Column (3) presents estimates for the mortality rate under-five years (calculated as the probability per 1,000 that a newborn baby will die before reaching age 5). The second-stage coefficient on income growth is in that case −27.1 and its SE is 8.2. It is thus significantly different from zero at the 1% level. Quantitatively the estimated effect of income growth is larger for five-year mortality than for infant mortality.

Next, we examine the effect that oil price–driven income growth has on countries' demographic composition. Consistent with our findings of income's effect on fertility and infant mortality, column (1) of Table 9 shows that income growth leads to significant increases in the share of the population aged 0–14. On the other hand, column (2) shows that there is a significant negative effect on the working-age population share (population aged 15–64).[13] Resonating these findings, column (4) shows that income growth leads to a significant increase in the child dependency ratio. Quantitatively, the coefficient of 0.16 suggests that a doubling of national income increases the child dependency ratio by about 0.16 units. In columns (3) and (5) we explore the effects that income growth has on the share of the population aged above 64 and the old age dependency ratio. The estimated effects are quantitatively small and insignificant. Column (6) shows that there is also no significant second-stage effect on the population ratio of females to males.

3.4. *Further Robustness Checks*

We have carried out a number of further robustness checks. We show in online Appendix B that our findings are robust to: excluding large positive and negative variations in GDP *per capita* growth, population growth and oil price shocks (online Appendix Table B2); using alternative data sources for countries' PPP GDP (online Appendix Table B3);[14] using GDP *per capita* growth over the past five years as the right-hand-side regressor (online Appendix Table B4); splitting the sample into rich and poor countries or excluding countries with very low or high GDP

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[13] Column (6) of Appendix Table A1 shows that the oil price instrument has no significant effect on immigration.

[14] Our main data source for countries' PPP GDP *per capita* is PWT 7.1. The reason for this is that this data source provides us with the largest number of country-year observations. Whereas PWT 7.1 provides PPP GDP data for 189 countries, PWT 8.0 has data for 167 countries only. Consequently, PWT 7.1 provides us with nearly 10% more observations than PWT 8.0 (4,428 as opposed to 4,096). For the World Development Indicators, the data availability on PPP GDP is much sparser: this database provides us with 2,118 observations thus about half the observations of the PWT 7.1.

Table 9

Effects of Income Growth on Demographic Structure

	ΔShare of population age 0–14	ΔShare of population age 15–64	ΔShare of population age 65+	ΔChild dependency ratio	ΔOld age dependency ratio	ΔFemale-to-male ratio
	(1) 2SLS	(2) 2SLS	(3) 2SLS	(4) 2SLS	(5) 2SLS	(6) 2SLS
GDP p.c. growth (10-year average)	0.05** (0.02)	−0.05*** (0.01)	0.00 (0.01)	0.16*** (0.05)	0.01 (0.01)	−0.01 (0.01)
Kleibergen Paap F-statistic	18.01	18.01	18.01	18.01	18.01	18.01
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4,452	4,452	4,452	4,452	4,452	4,452

Notes. The method of estimation is population-weighted two-stage least squares. The instrumental variable is the change in the international oil price between year t and $t-10$ multiplied by countries' average GDP share of net oil exports. Huber robust standard errors (shown in parentheses) are clustered at the country level. The dependent variable in column (1) is the change in the share of population aged 0–14 years. In column (2) the dependent variable is the change in the share of population aged 15–64 years. In column (3) the dependent variable is the change in the share of population aged 65 years and above. In column (4) the dependent variable is the change in the child dependency ratio (defined as the ratio of people ages 0–14 to the working-age population). In column (5) the dependent variable is the change in the old age dependency ratio (defined as the ratio of people older than 64 to the working-age population). In column (6) the dependent variable is the change in the ratio of female population to male population. *Significantly different from zero at 10% significance, **5% significance, ***1% significance.

per capita (online Appendix Table B5);[15] excluding large oil-importing countries from the sample (online Appendix Table B6); using an oil price instrument that is based on beginning of sample oil net-export GDP shares (online Appendix Table B7); controlling in the second stage for female labour force participation and immigration (online Appendix Table B8); splitting the sample based on whether countries have undergone a fertility transition (online Appendix Table B9).[16] We furthermore document in online Appendix B that the oil price instrument has no significant effects on alternative measures of innovation, such as R&D expenditures, scientific journal articles, patent applications and internet users (online Appendix Table B10); that there are no significant effects of the oil price instrument on TFP growth in relatively richer or poorer countries (online Appendix Table B11) and that there is no significant correlation between countries' oil net-export GDP shares and demographic structure (online Appendix Table B12).

[15] Strulik and Sikandar (2002) find a positive correlation between income and population at low thresholds of income but a negative correlation at relatively high income thresholds. Their correlations cannot be interpreted, however, as capturing a causal effect of income on population growth.

[16] Following Cervellati and Sunde (2011), we call a country pre-transitional if in 1960 the country's life expectancy is equal or below 50 years or the average crude birth rate is equal or above 30/1,000; a country is classified as post-transitional if in 1960 the life expectancy is above 50 years and the average crude birth rate is below 30/1,000.

4. Conclusion

The question whether and to what extent countries' income growth affects population growth has been in the focus of economic research since the beginning of the discipline. However, due to the endogeneity of national income, this question is difficult to answer empirically. Cross-country scatter plots between GDP *per capita* growth and population growth show a negative correlation (see Figure 1). The leading explanation of stagnant economic growth before the Industrial Revolution was that increases in income lead to increases in population size (Malthus, 1798). One reason for why this positive effect of income on population growth is not observed in correlational studies is that population growth could have a negative effect on GDP *per capita* growth. Another reason is that, in a Modern Growth Regime, there could be confounding factors that affect population growth beyond national income growth, for example, technological progress that raises national income as well as the opportunity cost of fertility (Galor and Weil, 2000).

This study's objective was to estimate the response of population growth to countries' income growth that is exogenous and unrelated to technological progress. To this end, we used for a panel of 139 countries spanning nearly half a century the change in the log of the international oil price interacted with countries' average net-export shares of oil in GDP as an instrument for GDP *per capita* growth. Another innovation of our empirical analysis is that we controlled for country and year fixed effects. The control for country fixed effects allowed us to account for time-invariant factors related to countries' geography, history and export structure that could affect both GDP *per capita* growth and population growth. The control for time fixed effects allowed us to account for world business-cycle effects.

The findings from our instrumental variables regressions suggest that countries' income growth has a significant positive effect on population growth: A 1 percentage point increase in GDP *per capita* growth over a 10-year period increases a country's population growth by around 0.1 percentage points. We documented that this result is robust to excluding countries located in the Middle East; excluding countries that are large oil importers and excluding from the sample large positive and negative observations of GDP *per capita* growth, population growth and oil price shocks. We also documented robustness to using initial shares of oil net exports in GDP to compute the oil price instrument or using five-year non-overlapping panel data. In terms of mechanism, the instrumental variables analysis showed that income increases that are independent of the technological development in a country increase a country's fertility rate. At the same time, there is a significant negative effect on infant mortality. This results in a strongly positive effect on surviving children which can also be detected in changes in countries' demographic composition.

Appendix A: Additional Regression Results

Table A1
Robustness Checks

	Population growth	Population growth	Female labour force participation rate	Ratio female-to-male labour force	Ratio female-to-male employment	Immigration
	(1) 2SLS	(2) 2SLS	(3)	(4)	(5)	(6)
			LS	LS	LS	LS
Dependent variable is:	Excl. large oil-importing countries	1970 net-export shares				
GDP p.c. growth (10-year average)	0.049** (0.022)	0.081*** (0.019)				
Oil price instrument (10-year average)			−0.011 (0.020)	−0.018 (0.026)	−0.029 (0.026)	2.25 (1.87)
Kleibergen Paap F-statistic	12.17	18.87				
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4,124	3,959	2,138	2,138	2,138	932

Notes. The method of estimation in columns (1) and (2) is population-weighted two-stage least squares; columns (3)–(6) population-weighted least squares. The instrumental variable in column (1) is the change in the international oil price between year t and $t-10$ multiplied by countries' average GDP share of net oil exports. The excluded countries in column (1) are China, France, Japan, the Netherlands, South Korea, US and the UK. In column (2) the instrumental variable is the change in the international oil price between year t and $t-10$ multiplied by countries' 1970 GDP share of net oil exports. *Significantly different from zero at 10% significance, **5% significance, ***1% significance.

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Additional Supporting Information may be found in the online version of this article:

Appendix B. Additional Regression Results.
Data S1.

References

Acemoglu, D. and Johnson, S. (2007). 'Disease and development: the effect of life expectancy on economic growth', *Journal of Economy, Political*, vol. 115(6), pp. 925–85.

Acemoglu, D., Johnson, S., Robinson, J. and Yared, P. (2008). 'Income and democracy', *American Economic Review*, vol. 98(3), pp. 808–42.

Acemoglu, D., Finkelstein, A. and Notowidigdo, M. (2013). 'Income and health spending: evidence from oil price shocks.' *Review of Economics and Statistics*, vol. 95(4), pp. 1079–95.

Becker, G. (1960) 'An economic analysis of fertility,' in (A.J. Coale, ed.), *Demographic and Economic Change in Developed Countries*, pp. 209–40, Princeton, NJ: Princeton University Press.

Black, D., Kolesnikova, N., Sanders, S. and Taylor, L. (2013). 'Are children 'normal'?', *Review of Economics and Statistics*, vol. 95(1), pp. 21–33.

Brueckner, M. (2012). 'Economic growth, size of the agricultural sector, and urbanization in africa', *Journal of Urban Economics*, vol. 71(1), pp. 26–36.

Brueckner, M., Chong, A. and Gradstein, M. (2012*a*). 'Estimating the permanent income elasticity of government spending: evidence on Wagner's Law based on oil price shocks', *Journal of Public Economics*, vol. 96(11), pp. 1025–34.

Brueckner, M., Ciccone, A. and Tesei, A. (2012*b*). 'Oil Price shocks, income, and democracy', *Review of Economics and Statistics*, vol. 94(2), pp. 389–99.

Caldwell, J. (1976). 'Toward a restatement of demographic transition theory', *Population and Development Review*, vol. 2(3/4), pp. 321–66.

Cervellati, M. and Sunde, U. (2011). 'Life expectancy and economic growth: the role of the demographic transition', *Journal of Economic Growth*, vol. 16(2), pp. 99–133.

Cotet, A. and Tsui, K. (2009). 'Resource curse or Malthusian trap? Evidence from oil discoveries and extractions.' Working Paper, Ball State University.

Cutler, D., Deaton, A. and Lleras-Muney, A. (2006). 'The determinants of mortality', *Journal of Economic Perspectives*, vol. 20(3), pp. 97–120.

Deaton, A. (2006). 'Global patterns of income and health: facts, interpretations and policies.' Working Paper No. 12735, National Bureau of Economic Research.

Feenstra, R., Lipsey, R., Deng, H., Ma, A. and Mo, H. (2004). 'World trade flows: 1962–2000', Working Paper 11040, National Bureau of Economic Research.

Feenstra, R., Inklaar, R. and Timmer, M. (2013). 'PWT: The next generation.' Working Paper 19255, National Bureau of Economic Research.

Galor, O. and Weil, D. (1996). 'The gender gap, fertility, and growth', *American Economic Review*, vol. 86(3), pp. 374–87.

Galor, O. and Weil, D. (2000). 'Population, technology and growth: from Malthusian stagnation to the demographic transition', *American Economic Review*, vol. 90(4), pp. 806–28.

Haber, S. and Menaldo, V. (2011). 'Do natural resources fuel authoritarianism? A reappraisal of the resource curse', *American Political Science Review*, vol. 105(1), pp. 1–26.

Haber, S., Razo, A. and Maurer, N. (2003). *The Politics of Property Rights: Political Instability, Credible Commitments, and Economic Growth in Mexico, 1876–1929*, Cambridge: Cambridge University Press.

Hamilton, J. (2009). 'Understanding crude oil prices', *Energy Journal*, vol. 30(2), pp. 179–206.

Hamilton, J. (2013). 'Historical oil shocks,' in (R.E. Parker and R. Whaples, eds.) *Routledge Handbook of Major Events in Economic History*, pp. 239–65, New York: Routledge.

Hassler, J., Krusell, P. and Olvoson, C. (2012). 'Energy-saving technical change.' Working Paper 18456, National Bureau of Economic Research.

Henderson, V. (2003). 'The urbanization process and economic growth: the so-what question', *Journal of Economic Growth*, vol. 8(1), pp. 47–71.

Herzer, D., Strulik, H. and Vollmer, S. (2012). 'The long-run determinants of fertility: one century of demographic change 1900–1999', *Journal of Economic Growth*, vol. 17(4), pp. 357–85.

Heston, A., Summers, R. and Aten, B. (2012). 'Penn world table version 7.1', Center for international comparisons of production, income and prices at the University of Pennsylvania.

Inklaar, R. and Timmer, M. (2013). 'Capital, labor, and TFP in PWT 8.0.' Working Paper, University of Groningen.

Jones, C. (2005). 'Growth and ideas', in (P. Aghion and S.N. Durlauf, eds.), *Handbook of Economic Growth*, Volume 1B, Chapter 16, pp. 1063–111, Amsterdam: Elsevier.

Jones, L.E., Schoonbroodt, A. and Tertilt, M. (2010). 'Fertility theories: can they explain the negative fertility-income relationship?', Working Paper 14266, NBER.

Lee, R.D. (1997). 'Population dynamics: equilibrium, disequilibrium, and consequences of fluctuations.' in (M. Rosenzweig and O. Stark, eds.), *Handbook of population and family economics*, Vol. 1B, pp. 1063–1115, Amsterdam: North-Holland.

Maccini, S. and Yang, D. (2009). 'Under the weather: health, schooling, and economic consequences of early life rainfall', *American Economic Review*, vol. 99(1), pp. 1006–26.

Malthus, T.R. (1798). *An Essay on the Principle of Population*, Oxford World's Classics, Oxford: University Press.

Miller, G. and Urdinola, P. (2010). 'Cyclicality, mortality, and the value of time: the case of coffee price fluctuations and child survival in Colombia', *Journal of Political Economy*, vol. 118(1), pp. 113–55.

Moeller, N.F. and Sharp, P. (2014). 'Malthus in cointegration space: evidence of a post-Malthusian pre-industrial England.' *Journal of Economic Growth*, vol. 19(1), pp. 105–140.

Murtin, F. (2013). 'Long-term determinants of the demographic transition, 1870–2000', *Review of Economics and Statistics*, vol. 95(2), pp. 617–31.

Pritchett, L. and Summers, L. (1996). 'Wealthier is healthier', *Journal of Human Resources*, vol. 31(4), pp. 841–68.

Smith, A. (1776). *An Inquiry into the Nature and Causes of the Wealth of Nations*, Oxford World's Classics, Oxford: Oxford University Press.

Staiger, D. and Stock, J. (1997). 'Instrumental variables regression with weak instruments', *Econometrica*, vol. 65(1), pp. 557–86.

Strulik, H. and Sikandar, S. (2002). 'Tracing the income-fertility nexus: nonparametric estimates for a panel of countries', *Economics Bulletin*, vol. 15(5), pp. 1–9.

UN (2010). 'Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects: The 2010 Revision', available at: http://esa.un.org/unpd/wpp/index.htm (last accessed: 18 February 2014).

UNCTAD (2011). 'United Nations Conference on Trade and Development', Commodity Price Series, available at: http://unctadstat.unctad.org/ReportFolders/reportFolders.aspx (last accessed: 1 January 2011).

WDI (2011). 'World development indicators', World Bank, available at: http://data.worldbank.org/data-catalog/world-development-indicators (last accessed: 18 February 2014).

Weil, D. (2007). 'Accounting for the effect of health on economic growth', *Quarterly Journal of Economics*, vol. 122(3), pp. 1265–306.

Weil, D. (2012). *Economic Growth*, Upper Saddle River: Prentice Hall.