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Industry location in Chinese provinces: Does energy abundance matter?☆

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ABSTRACT

We identify the driving factors of manufacturing activity across Chinese provinces with a particular focus on energy endowments. A model of production location is estimated, including both comparative advantage and economic geography determinants. The data set used consists of a panel of 28 Chinese provinces and 12 manufacturing industries over the period 1999–2009. Results confirm the relative importance of energy endowments. We find that larger energy endowments are significantly correlated with larger production of energy-intensive sectors. Disaggregation across energy carriers shows that coal exhibits the strongest impact. These results are robust across alternatives.

1. Introduction

Although energy resources have long been recognized as a crucial factor for long-run growth, their impact as a potential determinant of comparative advantage has received more attention only recently. The emerging evidence suggests that, along with other traditional determinants of comparative advantage and geographic concentration, energy endowments are significantly associated with specialization in energy-intensive products. This is verified both across nations (e.g. Gerlagh et al., forthcoming) and across subnational entities (e.g. Michielsen, 2013, for the US). However, the evidence is still scant, and more studies are required to strengthen the empirical support, with a particular emphasis on country or regional studies like the present one, which allow for a better control of unobserved trade barriers, technological differences and heterogeneous preferences. Hence we abstract from investigating international trade flows between China and the rest of the world. This is beyond the scope of this paper, although it is of great interest and should be addressed in future work. Given that trade-embodied CO_2 emissions, which are tightly linked to energy use, are much larger in interprovincial trade than those embodied in international trade (Guo et al., 2012), we are confident that our analysis is of empirical relevance.

This paper investigates the role of energy endowments in shaping the industrial specialization of Chinese provinces during the last decade. The Chinese case is interesting for at least four reasons. First, more than 30 years have passed since the pro-market reforms were launched at the end of the 70s, so it can be expected that the present locational decisions by firms are based on cost minimization, in particular energy costs in energy-intensive sectors. Second, China has overtaken Germany as the world's largest exporter in 2009 (WTO, 2010), confirming that structural change in China has also been impressive, not only its growth performance. Third, according to the estimates of the International Energy Agency, China may also have become the world's largest energy consumer (IEA, 2010). This is so because, in spite of government efforts and substantial improvements in energy efficiency, the Chinese production structure remains biased towards heavy industries (over the sample period 70% of total energy consumption is used in the industry and 54% in heavy industries). Fourth, Chinese provinces differ widely in terms of energy sources with energy-rich provinces mainly based in the North. Although the Chinese energy market is heavily regulated, energy-rich provinces can offer lower energy prices, in particular for those energy sources like coal, which are characterized by large transport costs.

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The empirical methodology is based on the previous analysis of the Chinese industrial structure by Batisse and Poncet (2004), who relied on the economic geography cum factor endowments model proposed by several recent studies in the field (e.g. Midelfart-Knarvik et al., 2001). We extend the existing literature by applying this model to Chinese provincial data over a reasonably long and recent time period (1999–2009) and by taking particular care of the relative importance of energy as a production factor. Energy carriers have high transport costs relative to their value (see Cristea et al., 2013), a treatment different from traditional intermediate goods is therefore justified. The paper tests the following three hypotheses: 1) Is industrial location in China determined by both new economic geography mechanisms and comparative advantages? 2) Is the activity of relatively energy intensive industries higher in relatively energy abundant provinces? and 3) Is the comparative advantage effect larger for immobile energy production factors that are subject to higher transport costs?

The next section outlines the literature review. The framework and methodological background are given in Section 3. Section 4 exposes the data sources, variable definitions and some stylized facts. Section 5 presents and discusses estimation results and Section 6 concludes.

2. Literature review

We provide a brief review of the main existing empirical frameworks used to analyze industry location and then present studies referring more specifically to the Chinese case.

2.1. Energy endowments and determinants of industrial location

There is an extensive literature illustrating how the predictions of the basic factor-endowment or Heckscher–Ohlin model (HO) can be improved by relaxing some key simplifying assumptions. Allowing for technological differences across countries, imperfect competition or transport costs substantially improve the explanatory power of the model. For example, Hakura (2001) shows that, by calculating a separate technological matrix for each of the four EU countries analyzed in 1970, the sign matches between factor endowments and trade orientation increase from 58% to 94%. By combining Krugman's (1980) monopolistic competition model and transport costs with the HO framework, Romalis (2004) obtains a deviation from factor price equalization which implies that locally abundant factors are relatively cheap. Therefore, relative industry output prices, which are built upon the interaction between industry and country characteristics (factor intensity and factor abundance) define a country's share in total production.

By endogeneizing the locational choice of firms facing transport costs and increasing returns to scale, the New Economic Geography approach (NEG) initiated by Krugman (1991) allows analyzing industry agglomeration and thereby the pecuniary effects of supply and demand linkages. These NEG forces have been proved to be important factors in firms' locational choices. Davis and Weinstein (1999) argue however that the downside of NEG is that it cannot include input composition and demand structure and that it therefore should be combined with determinants from the factor endowment theory. Hence, studies increasingly include both NEG and HO components. Of particular importance for the present study is the contribution of Midelfart-Knarvik et al. (2001), who include both HO and NEG effects into a common framework. Their empirical application is based on a panel of industries in 14 EU countries over the period 1980–1997, letting both country and industry characteristics interact. They suggest that growing economic integration in the EU has given way to a larger impact of both NEG and HO determinants of industry location. Note that industrial location models tend to perform better when the analysis is limited to a given region or country as this limits the problems linked to technological differences or barriers to trade (see e.g. Hakura, 2001; Kim, 1999).

Another frequent extension of the HO framework is to increase the number of factors considered. However, in spite of their economic, environmental and geopolitical importance, energy endowments have rarely been considered, and almost exclusively in the US case. Hillman and Bullard (1978) address the Leontief paradox (1954) by including energy as a production factor and not only as an intermediate input. The authors argue that the US is actually abundant in labor and capital but scarce in energy, which "distorts" the basic capital–labor trade-embodied calculations. Much later, using a combined HO–NEG framework Ellison and Glaeser (1999) include interaction variables on electricity, natural gas and coal endowments interacted with the corresponding intensities as determinants of employment shares. They find that the estimated energy interaction terms are quite large, explaining a substantial part of the total comparative advantage in US states over the period 1989–1991. Gustavsson et al. (1999) find that energy-intensive sectors tend to exhibit a larger coefficient of specialization (i.e. the ratio of domestic production to domestic consumption) in OECD countries with low energy prices, but the direction of causality remains unsettled. Klein and Crafts (2012) used coal abundance in relation with steam power use as a determinant for industry location in the US between 1880 and 1920. Only in 1880 a significant effect is observed.

Gerlagh et al. (forthcoming) assess the effects of energy endowments on trade using a panel of 14 OECD countries over the period 1970–1997. They find that energy-abundant countries have 7 to 10% higher employment and 13 to 17% point higher net exports per value added in energy-intensive sectors vis-à-vis otherwise comparable countries. Michielsen (2013) performs a country analysis on industry location in US regions, regressing value added on six different energy carrier interaction variables (electricity intensity with coal, natural gas and hydropower abundance and fuel intensity with oil and natural gas abundance) in addition to the usual factor endowment variables (labor, skilled labor and capital) and new economic geography interaction variables (market potential with economies of scale and intermediate input intensity). Energy endowments are found to play a significant role in determining US industrial activity.

To sum up, only very few studies have directly addressed energy in location studies. Apart from Klein and Crafts (2012), who focus on industry location in the US at the turn of the XIXth century, Gerlagh et al. (forthcoming) who look at OECD countries and Michielsen (2013) at US provinces, are, to the best of our knowledge, the only recent exceptions. In the present paper we use a similar framework to these last two papers, but focus on Chinese regions and include systematically new economic geography variables.

2.2. Industrial location and energy resources in China

Few studies have so far investigated the determinants of industry location for Chinese provinces. On the one hand, this could be explained by important constraints regarding data availability (e.g. information that varies across time, industries and provinces) and reliability (e.g. consistency between national and provincial data). On the other hand, market forces have only recently developed their effects on industry location. After three decades of a centrally planned economy, China generally reported a very weak degree of specialization across provinces, due to the central government's efforts to generate a widespread security of supply in case of foreign invasion. Young (2000, p. 7) argues: "With material supplies only ensured when one actually produced them oneself, and with the central regime actively encouraging and funding the local development of industries, each province, county, city and locality tried to develop its own duplicate set of industries." Herein lies the particular interest of a recent regional study on China: the opening reforms initiated in 1978 are still under development and have allowed market mechanisms to exercise a growing influence on economic activity. Nevertheless, as confirmed by the studies quoted below, the country continues to maintain high trade barriers at the international as well as the regional level, also impeding domestic trade. Protectionism not only limits geographic concentration and the benefits of specialization but also the free flow of goods across provinces, thus interfering with comparative advantage mechanisms. More recently Batisse and Poncet (2004) and Bai et al. (2003) indicate that beside protectionism, economic forces are observed to be at work in China and regional specialization has taken place. Industry location in China is therefore influenced both by industrial policy and economic factors. We are not aware of any direct investigation into the relative importance of these two determinants.[1] Although this would be of main interest, lacking a convincing policy proxy, we follow the literature and test only indirectly, by investigating whether standard economic factors do have an influence.

Regarding energy resources, in 2004 a national differential power pricing policy took effect, introducing specific tariffs with the objective to discourage further investment in energy intensive industries. Nevertheless, even accounting for these tariffs, the energy prices in China are, according to Lin and Liu (2010), lower than both the social and private equilibrium. Additionally, the provinces have significant possibilities to intervene and counterturn the policies of the central government. As Lin and Liu (2010) argue, the heavy industry in some remote provinces is a major source of taxation and is an important consumer of other industrial products. Following the 2008 crisis, many regional governments lowered the tariffs for energy-intensive industries and gave other incentives through tax reductions and subsidies. Thus, Chinese resource prices do not just reflect the abundance of energy endowments, but are also the result of regional energy and fiscal policies.[2] This is why we are using different measures of energy abundance and controlling for endogeneity issues in the regression analysis.

In short, in line with the recent literature, we include both Heckscher–Ohlin (HO) and new economic geography (NEG) factors to analyze industry location in China. Following Gerlagh et al. (forthcoming), Klein and Crafts (2012) and Michielsen (2013), we extend the work by Amiti and Javorcik (2008), Midelfart-Knarvik et al. (2001) and Batisse and Poncet (2004), by introducing energy sources as potentially important additional production factors.

We test the following three hypotheses:

Hypothesis 1. Is industrial location in China determined by both new economic geography mechanisms and comparative advantages?

Hypothesis 2. Is the activity of relatively energy intensive industries higher in relatively energy abundant provinces?

Hypothesis 3. Is the comparative advantage effect larger for immobile energy production factors that are subject to higher transport costs?

Hypothesis 1 is tested to see whether our general framework as proposed by Davis and Weinstein (1999) is applicable to the case of China over the study period. Hypothesis 2 investigates, whether energy should be introduced (beside traditional production factors such as capital and labor) as determinants of comparative advantages. This hypothesis has first been put forward by Hillman and Bullard (1978). Hypothesis 3 tests, indirectly, since we do not directly observe transport costs, whether the way to model differences in factor costs, as proposed in the seminal paper by Romalis (2004), is confirmed by our evidence.

3. Methodology

3.1. Theoretical background

As outlined in the above section, the theoretical background is directly inspired from the recent literature on industry location. Firms produce differentiated goods under economies of scale and compete on perfectly competitive markets which are partially segmented by transport costs and trade barriers. Locational decisions are based on factor costs, trade impediments, market potential and supplier access conditions. Midelfart-Knarvik et al. (2001) and Batisse and Poncet (2004) derive a theoretical model which has the following features:

- Transport costs: industry and province-pair specific iceberg costs
- Trade barriers: industry and province-pair specific constant ad valorem barriers
- Expenditure on products: aggregation of varieties according to a CES function
- Final good prices: proportional to marginal costs
- The number of varieties produced in each province is exogeneous and proportional to the size of the given industry and province (up to an error term)
- The composite intermediate is a Cobb–Douglas aggregate

The theoretical equation for relative output is then log-linearized and can directly be estimated.

3.2. Estimating equation

Hence we directly borrow the specification by Midelfart-Knarvik et al. (2001) and Batisse and Poncet (2004) where the left-hand side variable, a measure of relative output at the industry and province level, is explained by two groups of regressors, one related to HO effects, the other to NEG effects.

As in Gerlagh et al. (forthcoming) and Michielsen (2013), HO effects are captured by interaction terms obtained by the product between the relative factor endowment of the province and the relative factor intensity of the industry. The NEG effects are captured by indicators of demand linkages (market potential) and supply linkages (supplier access).

Using indices k, p, and t to indicate the industrial sector, the province and respectively the year, the basic empirical specification is given by:

$$\begin{aligned} Y_{k,p,t} = {} & \alpha_1\left(SKL_{ab}^{p,t} * SKL_{\text{in}}^{k,t}\right) + \alpha_2\left(CAP_{ab}^{p,t} * CAP_{\text{in}}^{k,t}\right) + \alpha_3\left(ENG_{ab}^{p,t} * ENG_{\text{in}}^{k,t}\right) \\ & + \beta_1 MKTP_{\text{ext}}^{k,p} + \beta_2 MKTP_{\text{int}}^{k,p} + \beta_3 SUPA_{\text{ext}}^{k,p} + \beta_4 SUPA_{int}^{k,p} + \gamma_{k,t} \\ & + \delta_{p,t} + \varepsilon_{k,p,t}. \end{aligned} \tag{1}$$

Definitions and dimensions of the variables are summarized in Table 1. The left-hand side variable in the main specification is simply the log of output of a given industry in a given province. Scale effects are captured by the sets of dummies included. In addition, following Batisse and Poncet (2004) and Midelfart-Knarvik et al. (2001) the left-hand-side variable is alternatively defined as the log of relative output, i.e. the ratio between output of industry k in province p, over the product of the share of province p in national output and the share of industry k in national output. This double standardization allows for comparisons between industries and provinces which vary widely in size.[3] Note that all abundance variables are expressed in per capita terms. If endogeneity is at work, the coefficients we find underestimate real effects (see also Michielsen, 2013 for this discussion).

The first line of Eq. (1) contains the HO variables, namely the interaction terms between factor abundance (ab) and factor intensity (in) for three primary factors i.e. skilled labor (SKL), capital (CAP) and total energy (ENG). All factor intensity terms are expressed in relative terms with respect to unskilled labor. For energy, we also consider an extension where ENG is replaced by three disaggregated energy sources: coal ($COAL$), petrol (OIL) and natural gas (GAS). This allows controlling for the degree of mobility between these energy carriers, with larger expected coefficients for coal, because it is characterized by larger transport costs.

The second line of Eq. (1) lists the NEG variables, which measure the proximity to both demand (market potential, $MKTP$) and suppliers of

[1] We thank an anonymous referee for pointing out this limitation of the literature.

[2] Note also that the production of oil and gas is dominated by a small number of state owned companies. In the econometric analysis dummy variables allow controlling for changes in regulation.

[3] The denominator can be interpreted as the "naïve" predictor of the particular industry–province output share, given average importance of both the industry and the province.

Table 1
Variable definitions and dimensions.

	Variable	Definition	Dimension
Explained variable	Y	log of output	Province–industry–year
Abundance (ab) variables	SKL_{ab}	log of university degree holders per capita	Province–year
(Country characteristics)	CAP_{ab}	log of total capital stock per capita	Province–year
	ENG_{ab}	log of total energy production	Province–year
		log of reserves per capita	Province
	$COAL_{ab}$	log of coal production/reserves per capita	Province–year
		log of reserves per capita	Province
	OIL_{ab}	log of petrol production per capita	Province–year
		log of reserves per capita	Province
	GAS_{ab}	log of natural gas production per capita	Province–year
		log of reserves per capita	Province
Intensity (in) variables	SKL_{in}	log of average wage rate per worker	Industry
(Industry characteristics)	CAP_{in}	log of industry capital stock per worker	Industry–year
	ENG_{in}	log of total energy consumption per worker	Industry–year
	$ELEC_{in}$	log of electricity consumption per worker	Industry–year
	OIL_{in}	log of petrol consumption per worker	Industry–year
	GAS_{in}	log of natural gas consumption per worker	Industry–year
NEG Variables	$MKTP_{ext}$	log of market potential from all other provinces	Province–industry
	$MKTP_{int}$	log of market potential within the province	Province–industry
	$SUPA_{ext}$	log of supplier access from all other provinces	Province–industry
	$SUPA_{int}$	log of supplier access within the province	Province–industry

Note: Details on variable sources, units and construction are given in Appendix IA and IB.

intermediate inputs (supplier access, *SUPA*). As mentioned in the literature review, China has large interior barriers to trade and exhibits quite a heterogeneous development across provinces. Therefore we split up the market potential into two components: an internal ($MKTP_{int}$) and an external ($MKTP_{ext}$) effect, which allows accounting for trade restrictions between provinces. A similar distinction is applied between internal and external supplier access. The detailed construction of the NEG variables, which is based on input–output relationships, is given in Appendix I.B.[4]

In the last line of Eq. (1), we find a white noise ($\varepsilon_{k,p,t}$) and dummy variables to control for unobserved heterogeneity i.e. industry–year fixed effects ($\gamma_{k,t}$) and province–year fixed effects ($\delta_{p,t}$). We also use in one specification industry–province fixed effects to test our findings. All regressions also include a dummy for coastal regions. Standard errors are clustered by province–industry or allow for general forms of cross-sectional (spatial) and temporal dependence using the Driscoll–Kraay[5] method.

3.3. Identification strategy

In order to be able to make statements not only about correlations, but also about causality, endogeneity issues must be discussed. Given that our dependent variable has a sector–country dimension and suitable fixed effects are introduced, we can safely argue that traditional country endowment variables (capital and labor) are not likely to be influenced by our lefthand side variable which influence would be too small if there would be any. The same holds true for the NEG variables (supplier access and market potential), which reflect the global economic structure and are not likely to be influenced by the economic activity of one sector in a given region. This can however not be excluded with certainty. Given that the NEG variables are not our main focus, but have ben introduced to control for other forces at work, we abstain from further investigations concerning this issue. Our variable of interest, energy abundance, depending on the precise measure we use, might however suffer from endogeneity issues. We therefore use in addition to the variable constructed on energy production, also lagged production, the self-sufficiency ratio and natural energy reserves (these variables are also used in Gerlagh et al., forthcoming).[6] Using lagged production (predetermined variable) allows us to preserve weak exogeneity. A severe test on the endogeneity issue is implemented, by using the self-sufficiency ratio (domestic energy production divided by domestic energy use). If countries with large energy-intensive sectors produce more energy, they will have a lower self-sufficiency ratio. Reverse causality would negatively bias the energy interaction coefficient. If similar results are obtained also with this measure (which will be the case here, as shown below), this suggests that the results are not driven by the endogeneity of our measure of energy abundance. The measure which best fits the ideal idea of an exogeneous variable are natural energy resources. This measure has the disadvantage of being constant over the sample period and hence allowing only for cross-regional variation.

4. Data

4.1. Data selection and preparation

Most of the data comes from the China Industrial Economic Yearbooks, which include detailed annual information for all 31 provinces in 25 manufacturing industries, some of which had to be aggregated to correspond to the input–output (IO) table definitions (see Appendix I.A. for a description of sources and construction of intensity and factor abundance variables). National IO-tables are available for 2002 and 2007 while a regional table is available for 2002.

Following previous studies on industrial activity in China (e.g. Batisse and Poncet, 2004), we decided to exclude three provinces and two industrial sectors from the analysis. Tibet is excluded because of its specific political situation and incomplete data, Xinjiang for its strong reliance on petrol and Hainan for its low industrial activity. Further, mining and extraction industries, and petroleum processing have been excluded since their location is almost uniquely defined by the location of natural resources. The industry variables are missing for 2004. We have linearly interpolated this information using data from 2003 and 2005. We end up with a balanced panel data set covering 12 industries in 28 provinces over the 1999–2009 period (see Table A1 for a list of the provinces and Table A2 for a list of sectors).

[4] Note that the construction of the NEG-variables based on consistent IO-Tables leads to the fact, that either the external or the internal variables must be linked positively to the dependent variable, when defined as output.

[5] Driscoll–Kraay standard errors account for heteroskedasticity, autocorrelation and contemporaneous correlation.

[6] Lacking energy prices, which are assumed to convey the effect of relative abundance to firms, we abstain from instrumental variable estimations.

Two particular cases are worth mentioning and will be further discussed in the Results and discussion section. First, capital intensity is captured by the value of net fixed assets over the number of workers. This variable was preferred to gross capital formation per worker (as used e.g. by Batisse and Poncet, 2004), because the latter reflects short term capital needs rather than long term endowments. Second, as measure of energy abundance, instead of using natural energy reserves in each province as proposed in Michielsen (2013), we opted for using energy production per capita as this gives a better indication of actual availability of the factors and includes the effects of eventual distorting policies on abundance. To limit possible endogeneity issues, we also use energy reserves and lagged energy production to proxy energy abundance. Furthermore, we interact electricity intensity, not with electricity abundance — as this is more likely endogenous to the provincial industry structure and population[7] — but with coal production per capita, as 80% of the electricity in China is generated in coal power stations.

4.2. Descriptive analysis

Regarding factor abundance we can see in Fig. 1a that there is no strong correlation between capital and energy abundance and a negative one if any. Capital-rich central provinces like Shanghai, Beijing or Tianjin, are not particularly well endowed in energy, while Northern provinces like Xinjiang or Inner Mongolia are among the largest energy producers although they are middle rank in terms of capital per capita. By contrast, Fig. 1b shows that there is a strong and positive correlation between capital endowment and the skill level of the labor force, suggesting that highly skilled workers tend to locate in capital-abundant provinces.

Regarding factor intensities on the industry level, Fig. 2a shows what one might expect: apart from the extreme case of petroleum products (excluded from the regressions), the paper, chemical, smelting and non-metallic mineral industries are the most intensive in energy use, are also intensive in capital use and, to a lesser extent, in skill level (Fig. 2b). Table A2 in the Appendix confirms that these four sectors also are the most energy-intensive for all energy carriers separately.

The HO framework assumes fixed factor intensities and factor endowments. However, Table 2 shows that for the time period between 1999 and 2009 for all factors relative to unskilled labor the average abundance across provinces and the average intensity across industries (with the exception of petroleum) are actually subject to important annual growth in China. This may seem contrary to other findings, in particular the decrease in energy intensity reported by Rosen and Houser (2007), but these later authors define energy intensity per unit of output instead of per worker, so the difference is mainly due to the large productivity increases experienced by China over the sample period.

Two additional stylized facts are in order. First, coal is the major energy carrier in China, where it represented 81% (71%) of primary energy production (consumption) in 2006. Second, there is a clear income gap between provinces on the coast and those inland. Fig. A1 in the Appendix exhibits that out of the 10 provinces with the highest GDP per capita, 9 are situated on the coast. Coastal provinces also trade substantially more with the rest of the world. This is not only due to the locational advantage, but also to economic policies of the Chinese government, in particular the establishment of the Special Economic Zones, since the 1970s (see e.g. Yueng et al., 2009).

5. Results and discussion

5.1. Hypothesis 1: HO and NEG location factors

Table 3 reports estimated coefficients for the determinants of industrial output including both HO and NEG factors. In columns (1) and (2), results from a traditional regression analysis with skilled labor and capital relative to unskilled labor and new economic geography variables are reported. While column (1) uses an estimate of the capital stock, column (2) uses gross fixed capital formation (GCF) as another proxy for capital endowments, used in other studies such as for example Batisse and Poncet (2004). However, this indicator has the disadvantage to be influenced by short term variations which are not relevant in the long-run HO approach, which is why it is not our preferred indicator.

As expected from theory, industries which use relatively intensively skilled labor tend to locate in provinces, which are relatively abundant in high skill workers. For both measures of physical capital we do find a negative and significant coefficient. This is not what the theory would predict. This may be due to measurement errors affecting the estimates of the capital abundance. Another possible explanation for these contradictory results is the phenomenon put forward by Rosen and Houser (2007), stating that provincial governments, especially in relatively energy abundant poorer provinces, strongly intervene in the localization of heavy industry which is not only energy but also capital intensive, leading to a strong distortion of industry localization. Hence, provinces relatively scarce in capital, actually attract capital-intensive industries and exhibit a larger than proportional activity in those industries. However this is only a conjecture. Note that the coefficient on physical capital turns positive and strongly significant in the final two columns with the more complete set of fixed effect province–industry.

The impacts of demand and supply linkages at the level of the province (*_int*) are significant and large, indicating that spillover effects between industries are important in determining industry location. The two external linkage effects (*_ext*) are insignificant suggesting that transport costs or protectionism between provinces prevent the exploitation of the gains from geographical concentration.

Hence, both classical HO factors and intra-province market externalities condition firms' location choices, confirming the choice of a framework where both determinants are included. These findings also show that part of Chinese industry location can be explained with economic theory (we mostly obtain the coefficients predicted by theory), but industrial policy still also seems to be a driving factor (the coefficient on capital is unexpected and some NEG coefficients are not significant). Unfortunately we are not able to identify the relative importance of these factors.

5.2. Hypothesis 2: The importance of energy endowments

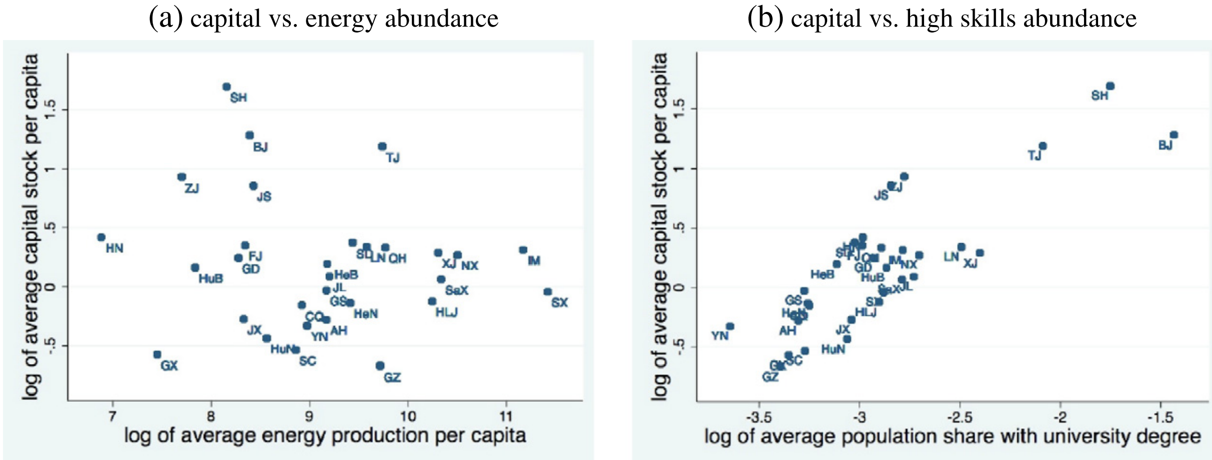
For column (3) to column (6) an interaction term for aggregate energy (relative to unskilled labor) has been included. The hypothesis that energy intensive industries locate in energy abundant regions is clearly validated in all specifications without changing significantly the other coefficients. Note that in column (4) all NEG variables become significant, the external market potential however negatively. This suggests the presence of market barriers between regions. While columns (1) to (4) include province–year and industry–year fixed effects, columns (5) and (6) include province–industry fixed effects absorbing most of the variation in the fixed effects (the NEG variables can no longer be included). The coefficient on energy becomes smaller but conveys the same message in terms of sign and significance as in the other specifications. Hence our findings on the importance of the energy interaction term are confirmed.

Energy seems to be a driving force in determining industry location next to the standard HO and NEG determinants.

5.3. Hypothesis 3: Differences across energy carriers

We turn to the third hypothesis, stating that the comparative advantage effect is expected to be larger for relatively immobile production factors that are subject to higher transport costs. Regressions in Table 4 report results with disaggregated energy interaction terms for

[7] Electricity production per capita is highly correlated with regional GDP per capita, implying that production is potentially linked to generally higher consumption in developed provinces.



Note: see table A1 for a province list including two-digit codes

Fig. 1. Average factor abundance across provinces. Note: see Table A1 for a province list including two-digit codes.

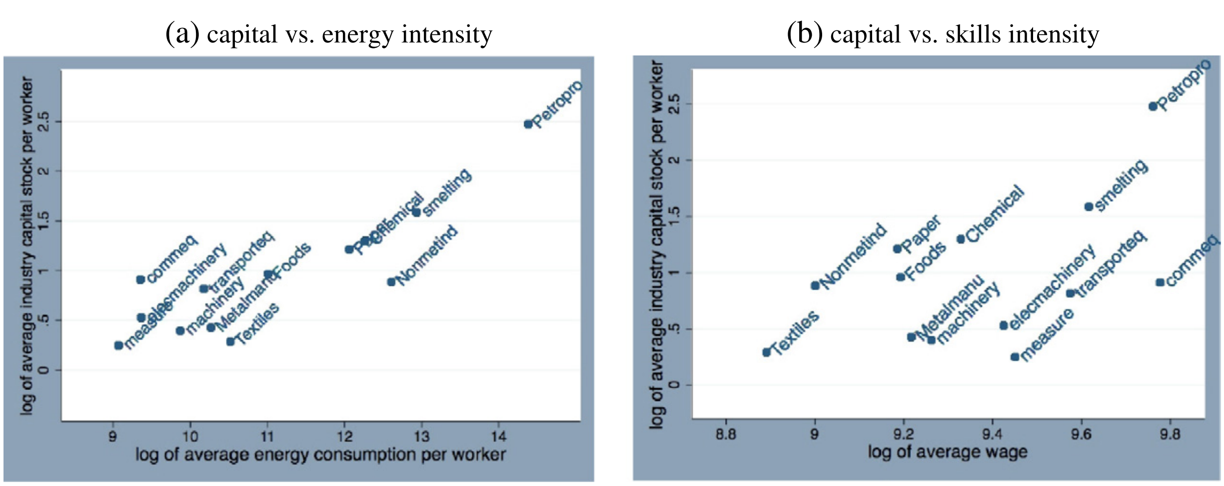
coal, oil and gas. While the interaction term on coal is positive and significant across all regressions, oil is only weakly significant and even negative. The interaction term on gas is positive but only weakly significant. Coal is considered to be relatively immobile featuring the highest onshore transportation costs and is also the most important energy resource in China (Remme et al., 2007).

Our hypothesis seems therefore confirmed, as coal is the most important determinant of industry location when coal, gas and oil enter the equation as separate energy carriers.

5.4. Robustness regressions

To check the robustness of our results, the preferred specifications in columns (3) and (4) of Table 3 are run with slightly different variable definitions. Tables 5 and 6 display these results. The first two columns of Table 5 are based on the dependent variable scaled by the product of the region and the sector shares, as used in Midelfart-Knarvik et al. (2001) and Batisse and Poncet (2004). In columns (3) and (4), following Michielsen (2013) variables have been standardized, such that all variables have zero mean and a standard deviation of one, such that the coefficients reflect the effect in terms of standard deviations of the dependent variable per standard deviation increase of the dependent variable. Hence the magnitude of the coefficients can be compared easily. Column (5) investigates temporal stability of the coefficient on the energy interaction term. A separate (additional) coefficient is estimated for the three earliest and the three latest years. Four observations can be made. First, previous results are confirmed, there is no real change in the coefficients. Second, the relative importance of the different factor abundance variables is of the same order of magnitude (see columns (3) and (4)). Third, the significance of the coefficient on the energy interaction term is higher when Driscoll–Kraay standard errors are used, pointing towards non-negligible correlations. Fourth, when testing for time stability of the energy coefficient, we see that the effect is significantly smaller at the end of the time period, but stays significantly positive at the 1% level even for the years 2007–2009. This reduction in the coefficient might be due to a combination of factors, such as energy imports, reduction in transport costs, and the fact that the relative importance of coal, the most immobile energy source, in total primary energy has slightly decreased over the sample period. Energy from oil and gas is easier to transport and hence abundance might matter less.

It can be argued that our measure of energy abundance is not exogeneously given but rather the consequence and not the cause of



Note: see table A2 for a sector list including short names

Fig. 2. Average factor intensities across industries. Note: see Table A2 for a sector list including short names.

Table 2
Average annual growth 1999–2009 of industry intensity and provincial abundance in percentages.

Factors	Intensity	Abundance
Capital	9.57	9.03
Skilled labor	NA	7.95
Energy	8.09	12.43
Electricity	8.99	10.80
Coal	8.54	12.26
Petroleum	−0.89	1.96
Natural gas	10.02	16.78
Industry output	20.45	

industry structure (e.g. a provincial government may subsidize energy production because its industry structure is biased towards energy-intensive products). To get a hand on this potential endogeneity bias, Table 6 reports results, where energy abundance is measured by lagged energy production, time-invariant proven reserves and the self-sufficiency-ratio (domestic energy production divided by domestic energy use). Results confirm previous findings. As expected, since it is a conservative estimate of the effect of energy abundance, the coefficient in column (3) is smaller but still significant at 5% level.

Overall results confirm basically the three hypotheses taken from theory. Most coefficients are significant and display the expected effects on industry location in Chinese provinces.

However, the coefficient on capital, some results for the NEG variables and the fact that important variables such as industrial policy and factor pricing are not taken into account also call for caution.

5.5. Discussion

Theory predicts that energy endowments affect industry location through energy prices. If indeed, as our results suggest, energy as a production factor is important for industry location, climate policy, which is changing energy prices, is going to affect industry location. So far the effects of climate policy as for example the magnitude of carbon leakage have mainly been estimated through simulation models. The present paper offers an alternative route, by following Gerlagh et al. (forthcoming) and Michielsen (2013) using statistical data to investigate the impact of energy availability on industry location.

This framework is satisfactory, inasmuch as it controls for human and physical capital endowments, and for the influence of backward and forward linkages. Disentangled from these effects, the impact of energy abundance turns out to be quantitatively as important as those of traditional endowments. However, due to lack of data, it fails to control directly for the influence of industrial and environmental policies, which are also expected to be important locational determinants. To better understand the link between theory and the observed results, energy prices and government policies would have to be factored in. This is left for future research.

6. Conclusions

In the context of a growing pressure on world energy resources, the consequences of China's exceptional growth performance on international energy markets have appropriately received a lot of attention. What has been more neglected so far is the question of the role of energy resources within China, as a determinant of industrial location across Chinese provinces. If this role is important, then energy policy deserves to be considered alongside investment or education policies to address the challenges of structural change. The evidence reported in the present paper suggests energy abundance matters.

We have analyzed the determinants of industrial location in China during the 1999–2009 period using a state-of-the-art empirical specification based on both traditional factor endowment motives and new economic geography determinants of locational choice, including proxies for energy abundance and intensities. In spite of some caveats regarding data quality, in particular estimates of the capital stock per

Table 3
Location determinants for Chinese manufacturing industries 1999–2009.

Ln(output)	(1)	(2)	(3)	(4)	(5)	(6)
Interaction terms						
SKL	0.860***	0.979***	0.865***	0.865***	0.087***	0.087***
	(0.272)	(0.303)	(0.279)	(0.063)	(0.006)	(0.022)
CAP	−0.570***		−0.558***	−0.558***	0.974***	0.974***
	(0.104)		(0.106)	(0.014)	(0.077)	(0.147)
CAP (GCF)		−0.589***				
		(0.107)				
ENG			0.065**	0.065***	0.016***	0.016***
			(0.027)	(0.013)	(0.004)	(0.003)
NEG variables						
MKTP_ext	−0.840	−1.072	−1.089	−1.089**		
	(0.831)	(0.971)	(0.852)	(0.461)		
MKTP_int	0.784***	0.880***	0.844***	0.844***		
	(0.211)	(0.226)	(0.212)	(0.065)		
SUPA_ext	1.140	1.722	1.132	1.132**		
	(1.209)	(1.399)	(1.174)	(0.572)		
SUPA_int	0.875***	0.761***	0.770***	0.770***		
	(0.216)	(0.237)	(0.222)	(0.031)		
Fixed effects and SE						
Industry–year	OK	OK	OK	OK	–	–
Province–year	OK	OK	OK	OK	–	–
Province–Industry	–	–	–	–	OK	OK
Clustered SE	OK	OK	OK	–	OK	–
Driscoll–Kraay SE	–	–	–	OK	–	OK
N	3558	3126	3558	3558	3558	3558
R-sq	0.826	0.831	0.828	0.828	0.480[a]	0.480[a]

Note: Standard errors in parentheses, clustering by province–industry; GCF: Gross Capital Formation, see Table 1 for other explanatory variable definitions.
** $p < 0.05$.
*** $p < 0.01$.
[a] Within R-squared.

Table 4
Disaggregated energy carriers.

ln(output)	(1) Energy production	(2) Energy production	(3) Lagged production	(4) Energy reserves
Interaction terms				
SKL	1.067***	1.067***	1.097***	0.833***
	(0.293)	(0.079)	(0.072)	(0.041)
CAP	−0.810***	−0.810***	−0.808***	−0.517***
	(0.128)	(0.019)	(0.013)	(0.039)
COAL	0.328***	0.328***	0.309***	0.005***
	(0.114)	(0.038)	(0.031)	(0.002)
OIL	−0.007*	−0.007**	−0.007***	−0.001
	(0.004)	(0.003)	(0.002)	(0.001)
GAS	0.007	0.007**	0.007**	0.003*
	(0.004)	(0.003)	(0.003)	(0.001)
NEG variables				
MKTP_ext	−0.817	−0.817**	−0.881**	−0.898**
	(0.802)	(0.401)	(0.422)	(0.432)
MKTP_int	0.790***	0.790***	0.805***	0.775***
	(0.204)	(0.061)	(0.055)	(0.060)
SUPA_ext	1.127	1.127**	1.233**	1.111*
	(1.152)	(0.566)	(0.601)	(0.568)
SUPA_int	0.809***	0.809***	0.820***	0.875***
	(0.216)	(0.030)	(0.030)	(0.020)
Fixed effects and SE				
Industry–year	OK	OK	OK	OK
Province–year	OK	OK	OK	OK
Clustered SE	OK	–	–	–
Driscoll–Kraay SE	–	OK	OK	OK
N	3558	3558	3234	3558
R-sq	0.831	0.831	0.823	0.826

Note: Standard errors in parentheses, clustering by province–industry.
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

Table 5
Relative shares, standardized variables and time stability.

	(1) Relative shares	(2) Relative shares	(3) Standardized variables	(4) Standardized variables	(5) Time stability
Interaction terms					
SKL	0.887***	0.887***	0.052***	0.052***	0.871***
	(0.287)	(0.080)	(0.017)	(0.005)	(0.064)
CAP	−0.553***	−0.553***	−0.064***	−0.064***	−0.560***
	(0.109)	(0.016)	(0.012)	(0.005)	(0.013)
ENG	0.069**	0.069***	0.047**	0.047***	0.091***
	(0.030)	(0.016)	(0.020)	(0.007)	(0.020)
ENG (1999–2001)					−0.035
					(0.026)
ENG (2007–2009)					−0.052**
					(0.023)
NEG variables					
MKTP_ext	−1.252	−1.252**	−0.521	−0.521**	−1.097**
	(0.969)	(0.578)	(0.407)	(0.203)	(0.460)
MKTP_int	0.836***	0.836***	0.406***	0.406***	0.843***
	(0.215)	(0.064)	(0.103)	(0.019)	(0.065)
SUPA_ext	1.389	1.389*	0.528	0.528**	1.133**
	(1.393)	(0.758)	(0.554)	(0.249)	(0.572)
SUPA_int	0.765***	0.765***	0.370***	0.370***	0.771***
	(0.228)	(0.033)	(0.108)	(0.034)	(0.030)
Fixed effects and SE					
Industry–year	OK	OK	OK	OK	OK
Province–year	OK	OK	OK	OK	OK
Clustered SE	OK	–	OK	–	–
Driscoll–Kraay SE	–	OK	–	OK	OK
Standardized variables	–	–	OK	OK	–
N	3558	3558	3558	3558	3558
R-sq	0.546	0.546	0.822	0.822	0.828

Note: Standard errors in parentheses, clustering by province–industry.
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

Table 6
Lagged production and reserves.

ln(output)	(1) Lagged production	(2) Energy reserves	(3) Energy self-sufficiency
Interaction terms			
SKL	0.887***	0.785***	0.790***
	(0.070)	(0.038)	(0.030)
CAP	−0.559***	−0.507***	−0.513***
	(0.012)	(0.027)	(0.035)
ENG	0.061***	0.003***	0.031**
	(0.010)	(0.001)	(0.013)
NEG variables			
MKTP_ext	−1.129**	−0.878**	−0.996**
	(0.478)	(0.427)	(0.480)
MKTP_int	0.857***	0.790***	0.797***
	(0.057)	(0.061)	(0.062)
SUPA_ext	1.241**	1.128*	1.156**
	(0.604)	(0.575)	(0.583)
SUPA_int	0.783***	0.862***	0.844***
	(0.027)	(0.020)	(0.026)
Fixed effects and SE			
Industry–year	OK	OK	OK
Province–year	OK	OK	OK
Driscoll–Kraay SE	OK	OK	OK
N	3558	3558	3558
R-sq	0.821	0.826	0.826

Note: Standard errors in parentheses, clustering by province–industry.
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

sector and province, and the lack of policy variables, the explanatory power of the model has been satisfactory and several robust results have emerged. First, both comparative advantage variables and supply and demand linkages are significant determinants of industrial output per region and sector. Second, differences in energy endowments are significant determinants and of similar importance as traditional factors of comparative advantages such as capital or skilled labor for industry location. Third, when relying on a disaggregated specification, the coefficient on coal is the largest and most significant among alternative energy sources, which is probably linked to the relatively important transport costs of coal with respect to more footloose alternatives like petroleum. This set of results is consistent with, and strengthens the emerging literature, on the importance of energy endowments as a source of comparative advantage.

It is fair to recognize that the conditions specific to China invite to taking the precise interpretation of results with a grain of salt, given that neither free flow of goods, nor identical technology matrices are confirmed in the Chinese context. As the applied specification does not include estimates of regional and international protectionist measures, room is left for a more profound analysis of interregional trade. With the continuing improvement and expansion of statistics published by the Chinese government, an extension of the model to different technology matrices may become possible. Taking care of the specific role of state-owned enterprises (SOEs) in energy markets and heavy industries is also a promising research avenue.

Nonetheless, note that the abovementioned findings could have an important impact on current and future Chinese environmental policies in two ways. On the one hand, national environmental policies directed towards energy consumption reduction which lead to energy price increases will increase the share of energy in production costs, thereby strengthening the role of energy prices as a locational motive. This may be expected to weaken the impact of the policy, as firms tend to relocate to regions with lower energy prices. On the other hand, the important influence and interventionist tendency of local governments, fostering and protecting certain industries, subsidizing heavy industries to which environmental policies are directed, prevents efficiency gains due to specialization and makes policy implementation more difficult. A better understanding of these politico-economic forces is warranted for China to cope with its huge environmental challenges.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.eneco.2014.05.005.

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