What's in a wedge? Taxation, Misallocation and the Oil Industry*

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Abstract

Differences in marginal revenue products (MRPs) across establishments can reflect the extent, but not necessarily the source of input misallocation. We use novel, concession-level tax data from the oil and gas industry to shed light on this issue. We confirm the existence of sizeable differences in gaps in MRPs between concessions operating within and outside the US. Once we account for variation in concession-specific revenue-taxation these gaps largely disappear. Harmonizing revenue-taxes world-wide to the extent observed in the US increases global oil and gas TFP by 25% and captures 93% of achievable gains associated with a shift to US-efficiency.

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1 Introduction

Cross-country differences in output per worker can largely be attributed to differences in Total Factor Productivity (TFP).[1] An important part of these TFP differences can be explained by the misallocation of capital and labor across firms. Hsieh and Klenow (2009), for example, find that productivity in China and India could have been 30-60% higher if inputs in those countries had been allocated as efficiently as in the United States. In this paper we ask the natural follow-on question: What is the source of this large misallocation of labor and capital across firms? Our findings point to differences in variation in revenue taxation as playing a key role - at least in the oil and gas industry.

The degree of misallocation is typically measured by examining the extent to which the marginal revenue products (MRPs) of individual inputs fail to equalize across firms.[2] Without misallocation, a firm wishing to maximize profits will increase the use of an input until its MRP is just equal to the cost of that input, implying perfectly equalized MRPs across firms. However, if two otherwise identical firms face, for example, two different capital tax-rates, this will give rise to a 'wedge' between MRPs: the MRP of capital will be higher for the high-tax firm and lower for the low-tax firm. The existence of this wedge is indicative of capital misallocation since together both firms could produce more goods if capital were reallocated from the firm with a low MRP to the firm with a high MRP.

In the above example, the source of misallocation is easy to identify and stems from the differences in capital tax-rates across firms. In the data however, there are many factors that can contribute to differences in MRPs (Restuccia and Rogerson, 2017). These may include - but are not limited to - variations in trade or transportation costs, borrowing constraints, political connectedness, institutional frameworks or even differences in geography and climate. Interpreting empirical MRP wedges and making meaningful policy recommendations based solely on their existence is thus problematic since identifying their exact source - and whether it stems from policy or other factors outside the control of the policy maker - is usually difficult mostly due to a lack of data.

This paper aims to shed some light on the source of variation in MRPs by focusing on the case of the upstream oil and gas industry. We proceed in three steps. First, we obtain a proprietary international database of the business activities of large oil and gas producers from Wood Mackenzie which we cross validate using data from Rystad Energy. This data set contains information on production, revenues, capital and labor costs and - crucially - tax payments for the universe of contracts of major oil and gas firms at the country-firm-concession level for over three decades. Second, we construct a simple heterogenous firms model in the spirit of Lucas (1978). Combining the model and the data, we calculate the variation in MRPs of labor and capital at the region-firm-concession level which in turn enables us to evaluate the degree of overall

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[1] See Caselli (2005), Hall and Jones (1999), Klenow and Rodriguez-Clare (1997).

[2] The MRP of an input is defined as the increase in a firm's total revenue attributable to employing an additional unit of that input.

misallocation in the global oil market. Finally, we make use of our detailed tax data to measure the proportion of variation in MRP that stems from variation in revenue tax rates. Globally, we find that nearly 58% of the variation in MRPs is accounted for by variation in revenue tax rates alone. Using our theoretical framework we measure the efficiency gains within the global oil and gas sector from a counterfactual tax harmonisation and compare it to the gains arising from a move to a perfectly efficient allocation of inputs. Harmonizing tax rates allows us to achieve 63% of total possible efficiency gains from eliminating all possible distortions. Variation in tax rates in the oil industry thus seems to be a key source of misallocation and inefficiency: harmonization could potentially result in a 25% increase in global TFP in the oil and gas sector.

Our paper connects to the large macro and growth literature that highlights the importance of misallocation for aggregate productivity.[3] Restuccia and Rogerson (2013, 2017) divide this literature into two different approaches. The first, so-called direct approach, examines misallocation that stems from specific and observable sources. The second, known as the indirect approach, identifies distortions as deviations, or 'wedges', from a particular model, enabling it to measure the total size of misallocation in an economy or market. Our paper combines both methods. It uses an indirect, model-based method to estimate total distortions in the global oil and gas market and then uses proprietary tax data to calculate misallocation directly by examining variation in revenue taxation and seeing what proportion of the former is explained by the later. In this way our analysis is complementary to Asker et al. (2019) who examine another aspect of distortions in the oil industry: the relative role of market power in total misallocation measured using actual industry cost curves. Whereas they use a model to measure the extent of market power, our measured distortions (revenue tax rates) are directly observable and model independent.

A challenge in this literature is to distinguish misallocation from other sources of dispersion in MRPs, such as differences in technology, measurement error, or different kinds of adjustment costs. Several recent papers have taken up this issue in relation to the manufacturing and the agricultural sector.[4] Haltiwanger et al. (2018) for example, argue that model-based MRP measures can potentially be misleading as they depend on the details of the chosen model. Besides these types of measurement problems, unavoidable tax or production inefficiencies may generate gaps in measured marginal products even in relatively undistorted economies such as the United States (Hsieh and Klenow, 2009; Restuccia and Rogerson, 2017). Similarly, our estimate of total misallocation might be attributing dispersion in MRP to misallocation when in fact it could be stemming from omissions or biases in the model or from mismeasurement. This would contribute to an *underestimate* of the role of taxation in misallocation as our model would predict more inefficiency than is actually present making it harder for variation in tax rates to account for this. To help address this point we make use of another key feature of our data. Whilst most of our sample is at the country level, for the United States (and Canada) we posses information at the regional, sub-national level. This enables us to use variation in MRPs and tax-rates in the USA

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[3] See for example, Guner et al. (2008), Restuccia and Rogerson (2008, 2013), Hsieh and Klenow (2009), Banerjee and Moll (2010), Garcia-Santana and Pijoan-Mas (2014), Hopenhayn (2014), Midrigan and Xu (2014) or Bento and Restuccia (2017).

[4] See for example, Rotemberg and White (2017), Haltiwanger et al. (2018), Pellegrino and Zheng (2021), White and Petrin (2018), Bils and Ruane (2020), Gollin and Udry (2021) or Herrendorf and Schoellman (2015).

as a baseline measure of dispersion when comparing it to dispersion in the Rest of the World (ROW). Since the ROW displays higher dispersion in both MRP and tax rates, we are able to use our data to measure the role played by differences in revenue tax rates between concessions in accounting for higher variation in MRPs in the ROW than in the USA. We find that variation in MRPs attributed to non-tax sources is near identical in both regions, however tax rates vary significantly more in the ROW than in the USA and this difference can account for 98% of the difference in variation in MRPs between the two regions.

Since our paper highlights the distortive effect of un-harmonized taxation, our work also relates to the literature on welfare losses associated with tax heterogeneity. For example, Fajgelbaum et al. (2019), study how the dispersion of US state taxes results in spatial misallocation and welfare losses to consumers. Desmet and Rossi-Hansberg (2013) argue that heterogeneity in regional taxes can have negative aggregate effects through a spatial misallocation of resources. Earlier studies of local public finance have similarly found that allocative efficiency will often require equal tax payments across locations (Flatters et al., 1974; Helpman and Pines, 1980). We find a similarly distortive role of tax-variation. Our model suggests that harmonising revenue tax-rates to the same extent in the ROW as is observed in the USA can increases TFP by approximately 25%. Crucially, this tax harmonization captures 93% of the gains generated from a shift in the ROW to "US Efficiency". This finding is especially interesting as many studies looking at evidence of misallocation arising from specific observable 'direct' sources - even taken together - find relatively small effects compared to measures of misallocation that identify distortions indirectly (Restuccia and Rogerson, 2017). Of course whether policy makers can feasibly implement such a tax harmonization across the international oil and gas industry - or indeed whether they would wish to, given the growing climate concerns associated with burning of fossil fuels - would depend on the costs and benefits associated with the complex process of negotiating any such international agreements. However, our research suggests, that policy makers looking to increase efficiency by reducing misallocation of inputs, would do well to investigate the role of taxation.

Finally, a potentially important source of variation in MRP stems from heterogeneity across production units (Gollin and Udry, 2021). In the oil and gas industry this may be especially important as the geological structure of oil and gas fields can vary dramatically across regions changing the way oil and gas is extracted.[5] Without taking this heterogeneity into account we may be attributing variation in MRPs to misallocation when in fact it is simply a consequence of geological differences giving rise to heterogenous production processes. This concern is partly addressed by treating the USA as a baseline since the variation in the geology of oil and gas fields within the US is vast and comparable to what is found in the ROW.[6] However, we can use our data's time dimension to address this important issue directly. In particular, we can allow for concession specific production functions that capture differences in geology (through its role on capital and labour elasticities) and examine the importance of tax-rate variation over time. In

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[5] For example, deep sea oil drilling in the gulf of Mexico or tar sand drilling in Alaska may be considerably more capital intensive than the easy surface drilling common in Saudi Arabia or Texas.

[6] More specifically, by treating the US as a baseline, we account for some 'background' level of variation in MRP that stems from geology.

the case of heterogenous production functions, we find that harmonizing taxes across concessions allows us to reach 90.3% of full efficiency gains globally and accounts for 95% of the higher gains in productivity in the ROW relative to the US. Thus, very clearly, our baseline results are not driven by this dimension of heterogeneity.

Whilst the findings of this paper are informative about the source of dispersion in MRPs and misallocation, it is important to emphasize that we focus only on a very specific sector. Although this is an important and large sector, we should be cautious generalizing findings in this industry to other sectors. First, effective tax rates in the oil and gas industry are typically higher than in other sectors due to the sheer size of the rents in the extractive industry. Second, major multinationals engaged in the extractive industry are undoubtedly extremely efficient in allocating capital and labor across locations, due both to their sheer scale and due to their political connections which potentially results in country specific regulations or borrowing constraints not being as binding as they would be for smaller firms in more traditional industries (Yergin, 1991). The estimated productivity gains in this paper offer some insight on the upper bound of the contribution of taxation to misallocation in other sectors, but more work remains to study the generalizability of the findings to other sectors.

In what follows section 2 introduces our data. In section 3 we construct a simple model which gives us a theoretical, indirect measure of concession-level MRPs and resulting wedges. Next, in section 4 we calibrate our model to the data whilst in section 5 we calculate wedges, and the variation in MRP, as well as the role played by revenue taxation in this variation. We also perform our counterfactuals and discuss the results in this section. Section 6 extends our model and uses the time series dimension of our data to examine production with heterogenous input elasticities. Section 7 investigates other potential sources of misallocation such as those between large and small firms, OPEC and non-OPEC firms, private and public firms, or within versus across firm tax variation. Finally, section 8 concludes.

2 Data

Overview We focus exclusively on the *upstream* oil and gas industry which is involved with extraction of resources, in contrast to *downstream* activities such as delivery or refining. The data for our main analysis has been provided to us by Wood Mackenzie - a prominent British consultancy in the energy sector - and is gathered by them in a variety of ways. First, they conduct face-to-face interviews with representatives from firms in the relevant country headquarters and examine official financial reports of these firms. Second, they collect information provided by country-specific and global regulatory authorities. Third, they use a large variety of media sources to fill in the blanks. We have been given access to data for 33 of the world's largest oil and gas producers for the period 1965 to 2013. Although Wood Mackenzie data is, in principle, available at the individual field or even individual well level, we only have access to an aggregated version of this data which, at its finest, is at the sub-national regional level (for Canada and the United States) and, at its coarsest, is at the national level (for all remaining countries). To increase our confidence in this data we conduct a triangulation exercise using data obtained from Rystad Energy - a Norwegian consultancy in the energy sector - for a sub-sample of our data. The analysis suggests that overall the data sets are comparable, which increases our confidence in the quality of the data (results are available upon request).

We start by placing the amount of output and revenues generated by our sample of 33 firms in perspective. These firms are responsible for a large majority of global oil production and a significant part of global natural gas production. In 2010, for example, they produced 58.4% of global oil output - approximately 49 million barrels of oil per day - and 30.2% of global natural gas output - approximately 17 million barrels of oil equivalent per day (BP, 2020). The gross revenue generated by the firms in our database amounted to 2.4% of global GDP in 2010 (WDI, 2016) - approximately equal to the size of the Russian, Canadian or Indian economies in the same year. By way of comparison, the analysis of misallocation by Hsieh and Klenow (2009) considered the manufacturing sectors of China, India and the United States. The combined value added of these relative to global GDP was approximately 6.04% in 2010 (WDI, 2016). The total gross revenue of firms in our sample is approximately 40% of the above figure. Thus our sample represents a significant portion of the global oil and gas industry and the world economy as a whole despite focusing only on a narrow sector.

Contract Types An important feature of our data is that it is divided according to the type of contracts that each firm signs with a corresponding government to obtain permission to extract natural resources in a given geographical area at a point in time. In particular, the exploration of a new geographical area by an oil firm is usually preceded by the creation of an agreement between the firm and the country hosting the firm. If the firm is granted 100% ownership of the product it extracts within a geographical area, the agreement is referred to as a *concession*. Agreements are referred to as *service contracts* if the firm is granted 0% ownership and as *production sharing agreements* if the firm is granted between 0 and 100% ownership. Such agreements imply that at least a share of the generated revenues by the firm is owned by the government of the country in which the firm is operating. As we will argue below, for reasons of comparability and simplicity, our focus in this paper will be on concessionary contracts only. Between 1965 and 2013, concession agreements represented on average 77.0% of all contracts. When weighting by the size of oil and gas output of each contract type, the importance of concessions was even higher - on average accounting for 87.3% of agreements between 1965 and 2013.

Data For each firm, geographical region, contract type and year we are given data on the total production of Gas and Liquids in thousands of barrels of oil-equivalent a day as well as a simplified cash flow statement that includes the following quantities: (1) Total Revenue which is the value that firm f generates in location i at time t by selling a specific quantity of oil and gas in current-year US\$, denoted by $\widetilde{PY}_{fi,t}$; (2) Capital expenditures which refer to the amount spent on durable goods (assets with lifetime > 1 year) in current-year US\$ which we denote by $\widetilde{I}_{fi,t}$; (3) Operational Costs which are calculated as the amount spent on labor and non-durable goods

Variable	Mean	Median	Standard Dev.	Max.	Min.	N
Production	0.4	0.1	1.4	12.7	0.0	2678
(1) Gross Revenues	6962.6	1137.4	24447.2	419435.4	1.3	2678
(2) Operational Expenditures	877.3	150.6	3213.7	43686.8	0.2	2678
(3) Capital Expenditures	739.9	160.0	1708.2	19039.0	-321.2	2678
Capital Stock	7488.8	2116.7	16851.6	154512.4	0.5	2678
(4) Total Government Take	4179.6	492.8	18872.2	350408.8	0.0	2678
(5) Cash Flow	1166.0	195.4	3917.8	45202.6	-14140.9	2678

Table 1: Summary statistics for baseline sample of concession-contracts. Production is in thousands of barrels of oil equivalent per day. The remaining variables are in millions 2010 constant US$. Notice that in the above the cash flow identity holds: (1)=(2)+(3)+(4)+(5).

e.g. (mostly) salaries and wages but also variety of other variables costs such as materials and maintenance costs in current US$ and are defined as $\widetilde{wL}_{fi,t}$. Throughout the paper we refer to this variable as labor costs, although this is of course a simplification. (4) Crucially, we also have data on Total Government Take which is the total amount of tax payments received by the government from firms in exchange for the rights to explore and extract oil and gas in a geographically defined area in current-year US$. We denote this quantity as $\widetilde{TGT}_{fi,t}$. (5) Finally, since the cash flow statement is an accounting identity, for each concession in every period we have information on cash flow in current-year US$, $\widetilde{CF}_{fi,t}$, defined as $\widetilde{CF}_{fi,t} \equiv \widetilde{PY}_{fi,t} - \widetilde{wL}_{fi,t} - \widetilde{I}_{fi,t} - \widetilde{TGT}_{fi,t}$. In the Appendix we make use of the capital expenditure data and the perpetual inventory method to calculate the implied capital stock held by firm f in location i at time t, which we define as $K_{fi,t}$.

Baseline Sample Throughout our analysis we will focus on a sub-sample of our data which we will call our baseline. Most importantly, for the following three reasons, we focus only on concession contracts. First, we wish to maintain comparability across production units when it comes to ownership structure. Second, concessions are characterized by a relatively simplified tax structure when compared to Production Sharing Agreements. This enables us to pin down the type of taxes we observe in our data with greater certainty. Third, the United States will serve as a crucial benchmark in our analysis when we compare US to non US-producers. Within our sample, US-producers only hold concessionary contracts. In order to allow for a like-for-like comparison we restrict our analysis to concession contracts.[7] Relative to our full sample, we also drop observations where either production or gross revenues are zero, as - similarly to Hsieh and Klenow (2009) - we wish to focus on concessions that are already producing, rather than concessions that are in the process of being commissioned.[8]

This leaves us with data for the period 1976 - 2013 and a total of 2678 observations, 189 country-

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[7] Notice, however, that since concessions form the overwhelming majority of oil contracts, looking at a broader sample would not qualitatively change any of our results - although it would make them harder to interpret.

[8] Importantly, there are only 153 of these data points, thus they represent a very limited fraction of the entire and baseline sample.

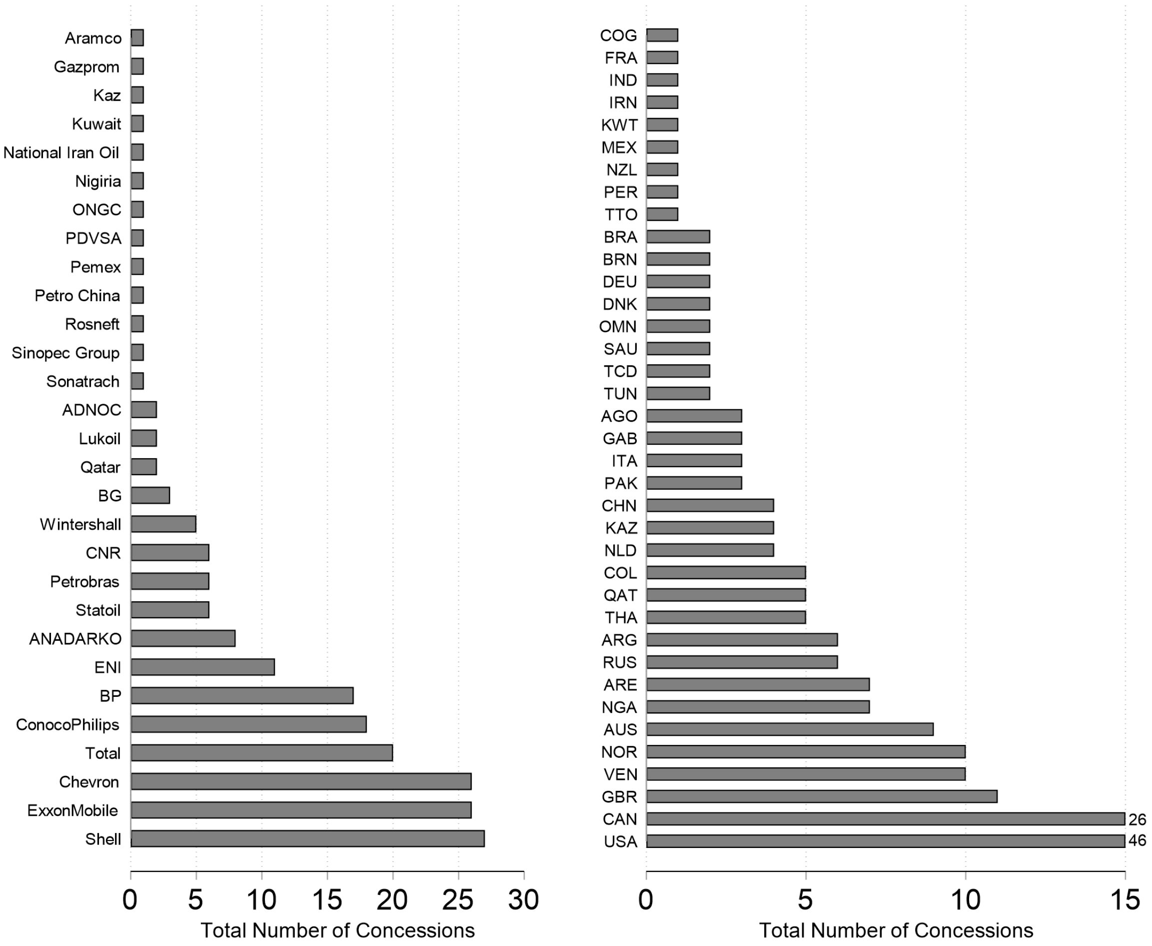
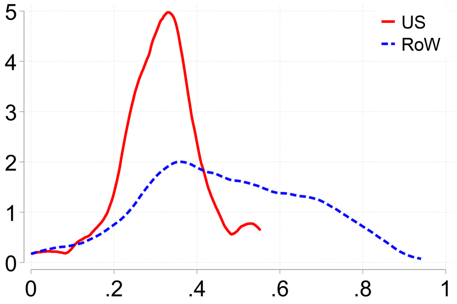


Figure 1: WoodMac Sample

firm-concession combinations consisting of 29 firms and 37 countries. The first panel of Figure 1 shows that our sample includes both single-country or single-concession firms (such as Aramco in Saudi Arabia or Gazprom in Russia) as well as large multi-national and multi-concession companies like Shell or ExxonMobile. The second panel of the Figure shows that the USA and Canada lead the list with the largest number of concessions granted to different companies - 46 and 22 respectively. Finally, Table 1 presents summary statistics for our baseline sample. Dollar values are expressed in constant 2010 US$ and are deflated using a USA GDP deflator (Feenstra et al., 2015). Production is presented in thousands of barrels of oil per day equivalent. Note that roughly one quarter of revenues are needed to cover capital and operational costs, implying that roughly three quarters of revenues - or 1-1.5% of global GDP - are shared between firms and governments in whose boundaries the firms are operating. Also note the large size of concessions. The average concession generates revenues of approximately 7.1 billion 2010 US$ annually, comparable to the GDP of a small country such as Fiji (7.4 billion US$ in 2010).

Fiscal Regimes The negotiation and the allocation of concession contracts varies across countries and depends on the existing petroleum laws and regulations (Johnston, 2007; Daniel et al., 1998; Venables, 2016). The total amount and the structure of payments received by governments under a concession are typically referred to as a petroleum fiscal regime. In some countries, a single fiscal regime applies to the entire country; in others, a variety of firm-specific regimes exist. In many cases, the concessions allocated to the same firm within the same country are also interlinked in a variety of ways. In short, the exact nature of a concession greatly varies across political jurisdictions (Global Oil and Gas Tax Guide 2019).

Our main variable of interest is the Total Government Take (TGT) which is the total amount of payments received by governments from firms in exchange for the rights to explore and extract oil and gas in a geographically defined area. This variable is closely linked to the contract signed between an oil company and a government. As discussed above, the TGT is determined by the petroleum fiscal regime and encompasses a variety of flows, such as bonuses, rentals, royalties, corporate income taxes, profit taxes and a number of special taxes. While the TGT is considered to be the most common statistic for the evaluation of petroleum regimes it has disadvantages, as any other measure (Johnston, 2007; Daniel et al., 1998). In particular, the TGT does not capture differences in the timing of payments, it does not adequately capture the risk associated with individual investments nor does it capture the ownership structure and the existence of non-pecuniary benefits (Johnston, 2007). Due to the static nature of our analysis and in particular our focus on concession-contracts rather than more complex ownership structures involving non-pecuniary benefits (such as product sharing agreements), our results are largely robust to such criticism. Importantly, throughout our analysis we treat TGT as a revenue tax defined as $\tau^V_{fi,t} PY_{fi,t}$ such that $\tau^V_{fi,t}$ may be thought as the average effective tax rate on the region-firm-concession level at time t. Although this is clearly a simplification that abstracts from the finer specifics of the fiscal regime, historically governments have overwhelmingly chosen revenue taxes in order to overcome asymmetric information problems associated with unobservable costs in exploration



(a) Kernel Density

Region	Mean	Median	Std	p90top10
USA	0.319	0.321	0.097	0.220
ROW	0.470	0.457	0.197	0.514
Diff	-0.151	-0.136	0.494	0.429

(b) Summary statistics.

Figure 2: Distribution of observed, concession-specific revenue tax rates, $\tau^V_{fi,t}$.

and extraction (Mintz and Chen, 2012).[9] Figure (2) shows the distribution of $\tau^V_{fi,t}$ in the USA and in the Rest of the World and provides some basic descriptive statics. Note that $\tau^V_{fi,t}$ is far more dispersed in the ROW than the USA - with a variance that is more than 4 ($\approx 0.197^2/0.097^2$) times higher.

3 Model and Efficiency

In this section we construct a standard span-of-control model that allows us to extract the marginal revenue products of labor and capital across firm-location pairs in the oil sector. The dispersion of these marginal revenue products is indicative of the total misallocation of inputs across firm-location pairs. Using data on revenue taxation at the firm-location level we will then be able to measure 1) the extent to which dispersion in taxation alone can account for dispersion in marginal revenue products and 2) the size of efficiency gains from tax harmonization relative to efficiency gains stemming from complete harmonisation of marginal revenue products. Both exercises will provide measure of the importance of variation in taxation in observed factor misallocation.

Model Suppose the world is divided into I locations denoted by $\mathscr{I} \equiv \{1, \ldots, I\}$ and that there are F firms denoted by $\mathscr{F} \equiv \{1, \ldots, F\}$. Each location $i \in \mathscr{I}$ can grant any firm $f \in \mathscr{F}$ a *concession agreement*: the right to extract resources within its geographic boundaries.[10] All

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[9] More recently, countries have started moving towards fiscal regimes that rely more on profit-based taxation (see Mintz and Chen (2012) for an excellent survey and discussion). Since our analysis stops in 2013 - this is less of an issue than if we were examining more recent data. Ideally, of course, we would differentiate between revenue and other forms of taxation, however our data does not allow for that.

[10] Specifically, a concession is an agreement between a sovereign government and a firm that grants the firm the (potentially non-exclusive) right to extract oil and gas in a strictly defined geographic area as well as ownership over

concession agreements are summarized by the matrix, $C \equiv (c_{fi}) \in \mathbb{R}^{F\times I}$, where $c_{fi} = 1$ if firm f has been granted a concession agreement in location i and $c_{fi} = 0$ otherwise. C is assumed to be constant, which excludes the possibility of all entry or exit. We also assume that all fixed startup or exploration costs have already been paid in order to abstract from the investment process and focus on ongoing production.[11] More formally, $\bar{\mathscr{I}}$ represents the set of all firm-location pairs that have a concession agreement in place and production is ongoing, $\bar{\mathscr{I}} \equiv \{(f,i) \in \mathscr{F} \times \mathscr{I} | c_{fi} = 1\}$. The basic unit of production is a firm-location pair belonging to this set, which we will refer to as a *concession*. Every concession $(f,i) \in \bar{\mathscr{I}}$ is characterized by the following production function:

$$(1) \qquad Y_{fi} = A_{fi}(K_{fi})^{\gamma}(L_{fi})^{\alpha}.$$

In the above, Y_{fi}, L_{fi} and K_{fi} are output, labor and capital of firm f in location i respectively whilst A_{fi} is the corresponding, exogenous Total Factor Productivity (TFP). In the tradition of span-of-control models, our production function exhibits decreasing returns to scale with respect to labor and capital such that $\alpha, \gamma \in (0,1)$ and $0 < \alpha + \gamma < 1$. This characteristic captures the existence of fixed assets such as oil reserves or company specific know-how which is required to operate each concession and gives rise to positive economic profits. Each firm f's objective is to maximize total profits, π_f, across all locations in which it holds concession agreements $\mathscr{I}_f \equiv \{i \in \mathscr{I} | c_{fi} = 1\}$ by choosing K_{fi} and L_{fi}:

$$(2) \qquad \pi_f = \max_{L_{fi},K_{fi}} \sum_{i\in\mathscr{I}_f} \left(P(1-\tau^Y_{fi})Y_{fi} - wL_{fi} - r(1+\tau^K_{fi})K_{fi} \right).$$

Firms take the price P of oil, wage rates w, and capital rental rates r, as given.[12] Each concession faces a number of exogenous distortions - or wedges. Since there are two factors of production, we can separately identify distortions that affect both capital and labor from distortions that change the marginal product of one of the factors relative to the other factor. We denote distortions that increase the marginal products of capital and labor by the same proportion as an output distortion (τ^Y_{fi}) and distortions that raise the marginal product of capital relative to labor as a capital distortion (τ^K_{fi}). Distortions capture a range of factors such as differences in mobility of capital or taxation across concessions and give rise to wedges between market and concession-specific prices that result in a misallocation of inputs across concessions.

Finally, notice that although the above problem is written in static-form (and hence all time subscripts are dropped), in the Appendix we show that the above can easily be re-written as a dynamic cash-flow maximization problem from the perspective of the firm as a capital

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the extracted resources - in exchange for a variety of tax payments. As mentioned, in our data, the geographic coverage of each concession almost always coincides with an entire country - with the exception of the United States and Canada - where concession data is aggregated at sub-national levels.

[11] Thus, like Hsieh and Klenow (2009), we are interested only in the intensive - rather than the extensive - margin of production.

[12] This assumption stems from the fact that oil is a highly homogenous tradable good whilst capital and labor inputs are - at least potentially - very mobile within the oil industry. With the exception of a small share of low-skilled workers, labor and capital are routinely shipped around the world.

accumulator. Since the first order conditions of the two problems are identical, in the main body of the paper we refer only to the simpler, static version of the problem.

Distortions and Marginal Revenue Products: To highlight the distortive role of wedges, we use (2) to derive expressions for optimal capital and labor allocations at each concession:

$$(3) \qquad K_{fi} = \left(P \left(\frac{\gamma}{r}\right)^{1-\alpha} \left(\frac{\alpha}{w}\right)^{\alpha} A_{fi} \frac{(1-\tau^{Y}_{fi})}{(1+\tau^{K}_{fi})^{1-\alpha}} \right)^{\frac{1}{1-\alpha-\gamma}}, L_{fi} = \left(P \left(\frac{\gamma}{r}\right)^{\gamma} \left(\frac{\alpha}{w}\right)^{1-\gamma} A_{fi} \frac{(1-\tau^{Y}_{fi})}{(1+\tau^{K}_{fi})^{\gamma}} \right)^{\frac{1}{1-\alpha-\gamma}}.$$

Concessions with higher productivity will use more inputs, ceteris paribus. Input allocation however also depends on concession-specific distortions. Higher output distortions at a concession, τ^{Y}_{fi}, will result in fewer inputs being allocated to that concession (ceteris paribus). Furthermore, since $K_{fi}/L_{fi} \propto 1/(1+\tau^{K}_{fi})$, higher capital distortions at a concession will lead to relatively less capital than labour being allocated to that particular concession. The extent to which input allocation is driven by differences in distortions rather than by TFP, can be summarized by the dispersion of the marginal revenue products of labor (MRPL) and capital (MRPK):[13]

$$(4) \qquad MRPL_{fi} = \alpha \frac{PY_{fi}}{L_{fi}} = \left(\frac{1}{1-\tau^{Y}_{fi}}\right) w \quad \text{and} \quad MRPK_{fi} = \gamma \frac{PY_{fi}}{K_{fi}} = \left(\frac{1+\tau^{K}_{fi}}{1-\tau^{Y}_{fi}}\right) r.$$

Since labour and capital are free to move across concessions, wages and rental rates measured net of distortions, will equalize across firms and locations. Marginal revenue product (MRP) however, will be higher in concessions that face disincentives, and lower in concessions that benefit from implicit or explicit subsidies. For convenience, we will summarize the extent of input misallocation at a specific concession using a geometric average of input-specific MRPs:

$$(5) \qquad MRP_{fi} \equiv (MRPK_{fi})^{\frac{\gamma}{\alpha+\gamma}} (MRPL_{fi})^{\frac{\alpha}{\alpha+\gamma}}.$$

A useful feature of the above measure is that it captures the extent to which concession *output* is driven by distortions rather than by TFP.[14] Furthermore, MRP is directly comparable to the measure of revenue productivity (TFPR) used by Hsieh and Klenow (2009) since their measure of TFPR is a geometric average of marginal revenue products of capital and labour at the plant level. In what follows we will measure the role of taxation in the observed dispersion of this measure.

Distortions and productivity Dispersion in measured MRPs is symptomatic of misallocation and hence lower productivity and output. To measure the cost of misallocation we proceed by

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[13] To see this, notice concession inputs can be written as functions of $MRPK$ and $MRPL$: $K_{fi} = \left(\frac{A_{fi}\gamma^{1-\alpha}\alpha^{\alpha}}{(MRPK_{fi})^{1-\alpha}(MRPL_{fi})^{\alpha}}\right)^{\frac{1}{1-\alpha-\gamma}}, L_{fi} = \left(\frac{A_{fi}\gamma^{\gamma}\alpha^{1-\gamma}}{(MRPK_{fi})^{\gamma}(MRPL_{fi})^{1-\gamma}}\right)^{\frac{1}{1-\alpha-\gamma}}$.

[14] Using (1) and (3) we can write output as a function of MRP: $Y_{fi} = \left(A_{fi}^{\frac{1}{\alpha+\gamma}} \gamma^{\frac{\gamma}{\alpha+\gamma}} \alpha^{\frac{\alpha}{\alpha+\gamma}} / MRP_{fi}\right)^{\frac{\alpha+\gamma}{1-\alpha-\gamma}}$.

finding the equilibrium of the model. Using (3) we obtain an expression for the equilibrium allocation of labor and capital for each concession operating within any arbitrary region (i.e. grouping of locations) $J \subseteq \mathscr{I}$:

$$L_{fi} = \frac{\widetilde{A}_{fi}}{\sum_{\bar{J}} \widetilde{A}_{fi}} L_J \quad \text{and} \quad K_{fi} = \frac{\widehat{A}_{fi}}{\sum_{\bar{J}} \widehat{A}_{fi}} K_J, \tag{6}$$

where $\bar{J} \equiv \{(f,i) \in \mathscr{F} \times J | c_{fi} = 1\}$ denotes the set of concessions operating in region J, $L_J \equiv \sum_{\bar{J}} L_{fi}$ and $K_J \equiv \sum_{\bar{J}} K_{fi}$ are the total labor and capital employed within that region, whilst

$$\widetilde{A}_{fi} \equiv \left(\frac{A_{fi}}{MRPK_{fi}^{\gamma} MRPL_{fi}^{1-\gamma}} \right)^{\frac{1}{1-\alpha-\gamma}} \quad \text{and} \quad \widehat{A}_{fi} \equiv \left(\frac{A_{fi}}{MRPK_{fi}^{1-\alpha} MRPL_{fi}^{\alpha}} \right)^{\frac{1}{1-\alpha-\gamma}}, \tag{7}$$

are distortion-adjusted concession productivities.[15] We close the model by assuming that the total amount of capital and labor at the global level is fixed, i.e. $L_{\mathscr{I}} \equiv L$ and $K_{\mathscr{I}} \equiv K$, for some constant L and K.[16] Using the above solutions and the production function (1), we obtain expressions for aggregate productivity (D_J) and output (Y_J) for any region $J \subseteq \mathscr{I}$:

$$D_J \equiv \sum_{\bar{J}} A_{fi} \frac{\overline{A}_{fi}^{\alpha+\gamma}}{(\sum_{\bar{J}} \widehat{A}_{fi})^{\gamma} (\sum_{\bar{J}} \widetilde{A}_{fi})^{\alpha}} \text{ and } Y_J = D_J K_J^{\gamma} L_J^{\alpha}, \tag{8}$$

where $\overline{A}_{fi} \equiv \left(\frac{A_{fi}}{MRP_{fi}} \right)^{\frac{1}{1-\alpha-\gamma}}$ is a distortion-adjusted productivity measure. Thus, aggregate productivity is simply a weighted average of concession-level productivities with higher weight given to more productive and less distorted concessions. If MRPs were equalized across concessions, aggregate TFP of region J would be given by: $D_J^* \equiv \left(\sum_{\bar{J}} A_{fi}^{\frac{1}{1-\alpha-\gamma}} \right)^{1-\alpha-\gamma}$. In what follows, this undistorted, counter-factual level of productivity will serve as an important benchmark against which we measure importance in variation of revenue taxation and total distortions.

Revenue Taxes We are interested in quantifying the extent to which the input misallocation defined above is accounted for by inter-concession differences in direct revenue-taxation. To this end, we will be decomposing output distortions (τ_{fi}^{Y}) into their directly observable tax component

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[15] Notice that whilst measures of MRPL and MRPK in $\widetilde{A}_{fi}$ and $\widehat{A}_{fi}$ contain equilibrium prices, since only relative values matter in (6), these cancel out for the expression as a whole.

[16] This is not a particularly strong assumption given our static model, since it takes quite some time to educate engineers and drillers and it typically takes 2-3 years to build a new rig (Lamont, 2017). Moreover, neither the skills of a driller nor the capital embodied in an oil rig are easily transferrable to other sectors.

(τ^V_{fi}) and their implicit wedge component (τ^W_{fi}) so that:

$$(9) \qquad (1-\tau^Y_{fi}) \equiv (1-\tau^V_{fi})(1-\tau^W_{fi}).$$

We will then measure the relative importance of τ^V_{fi} in accounting for variation in MRPs in a number of different ways.

4 Calibration

Next, we calibrate our model which will enable us to: measure output wedges (τ^W_{fi}) and capital distortions (τ^K_{fi}); to quantify the effect of these distortions on productivity; and to measure the role of revenue taxation in this process. We set the real rental price of capital (excluding distortions) to $r = 0.1236$. This includes a 5% real interest rate and a 7.36% depreciation rate which we obtain as the average Implied Depreciation Rate for Private Nonresidential Fixed Assets of the Oil and Gas sector between 1976 and 2013 from the BEA (2020). The actual cost of capital at concession fi is given by $(1+\tau^K_{fi})r$, and so it differs from 12.36% if $\tau^K_{fi} \neq 0$.[17]

Next, we calibrate capital and labour elasticities. We assume that median non-tax distortions across concessions in the USA are zero, i.e. $\overline{\overline{(\tau^K_{fi})}}_{fi\in \bar{USA}} = \overline{\overline{(\tau^W_{fi})}}_{fi\in \bar{USA}} = 0$. Then, using this assumption and (4), we obtain:

$$(10) \quad \alpha = \overline{\overline{\left(\frac{wL_{fi}}{(1-\tau^V_{fi})PY_{fi}}\right)}}_{fi\in \bar{USA}} = 0.264 \quad \text{and} \quad \frac{\alpha}{\gamma} = \overline{\overline{\left(\frac{wL_{fi}}{rK_{fi}}\right)}}_{fi\in \bar{USA}} = 0.708.$$

Combining these two equations implies that $\gamma = 0.373$. There are three reasons why we choose to calibrate to US concessions. First, we follow Hsieh and Klenow (2009) in assuming that the US is a relatively undistorted benchmark and any wedges that do exist are likely to stem from model misspecification. Effectively, this is a useful normalization that does not have any impact on our results.[18] Second, our data on US concessions is at the sub-regional level which allows us to estimate the respective variations of capital and labor wedges within the US. Finally, due to its geographic size, the US is highly diverse in the types of oil fields it possesses - from conventional and tight oil wells through to deepwater oil and oil sands. Calibrating elasticities to the median concession in the US thus arguably allows us to obtain a good approximation of global median elasticities.[19]

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[17] Since rental rates are in real terms, we are implicitly deflating all nominal values using the price of US GDP obtained from Feenstra et al. (2015).

[18] Furthermore, there is strong evidence of relatively low distortions in the US which suggests a limited influence of regulations on economic activity and suggests that non-tax wedges should be small. For example, the US consistently tops the *Doing Business* evaluation conducted by the World Bank.

[19] The choice of elasticities does not influence our later calculations of variances of MRPL and MRPK. However,

Finally, using the above parameters and the concession level data we discussed earlier, we can infer distortions and productivity at each concession as:

$$(11)\quad 1-\tau^{W}_{fi}=\frac{1}{\alpha}\frac{wL_{fi}}{(1-\tau^{V}_{fi})PY_{fi}}$$

$$(12)\quad 1+\tau^{K}_{fi}=\frac{\gamma}{\alpha}\frac{wL_{fi}}{rK_{fi}}$$

$$(13)\quad A_{fi}=\kappa\frac{PY_{fi}}{(K_{fi})^{\gamma}(wL_{fi})^{\alpha}}.$$

The first two equations come from a re-arrangement of (4). We infer non-tax distortions in output if labour's share in after-tax income differs from what one would think it should be compared to labor elasticity. Non-tax distortions in capital are similarly inferred when the ratio of labor compensation to the capital stock is differs from what one would expect given the output elasticities with respect to capital and labor. In the final equation we calculate concession-specific productivity within our framework, by rearranging equation (1). The scalar κ is given by $\kappa = w^{\alpha}/P$ and whilst we do not observe κ directly, relative productivities - and hence reallocation gains as well as labor and capital shares - will be unaffected by setting $\kappa = 1$.[20]

The distribution and summary statistics of the above concession-specific measures of distortions are presented in Figures 3 and 4. By construction, median non-tax distortions to output and capital are zero in the USA. The median non-tax output wedge in ROW is indistinguishable from that of the USA. The median distortion to capital is lower in the ROW than in the USA - indicating implicit subsidies in the ROW relative to the USA. Notice also that the standard deviation of non-tax distortions is actually slightly larger in the USA than in the ROW - although the differences are not big.

Figure 5 shows the distributions of (the log of) concession productivities in the USA and the ROW - normalized by the average of the (log of) world TFP.[21] Notice that the productivity of concessions located in the USA is lower than in the ROW. This is not surprising, since our productivity measure captures the size of oil and gas reserves which are much larger in the ROW than the USA. This intuition is confirmed when looking at the standard deviation of productivities. Notice that the ROW exhibits greater variation in productivity and that this variation is predominantly driven by the fat, right tail of the distribution - generated by concessions in countries like Saudi Arabia

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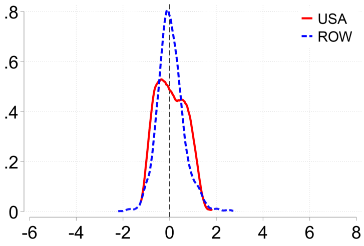
since MRP is a weighted average of MRPL and MRPK (with elasticities directly influencing the weights), the choice of elasticity will influence the variance of MRP.

[20] We take this approach as we do not have data on employment - but only its values. We do have data on oil and gas quantities however results remain largely unchanged when using this instead.

[21] Data is pooled over time and re-normalized for each year. Very similar results hold when looking at specific years in isolation.

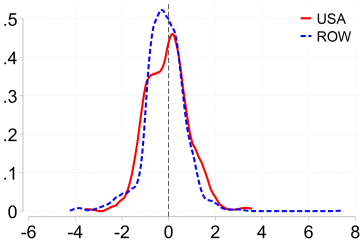


(a) Kernel Density

Region	Mean	Median	Std	p90top10
USA	0.064	0.000	0.620	1.657
ROW	0.038	-0.005	0.571	1.373
Diff	0.025	0.005	1.084	1.207

(b) Summary statistics.

Figure 3: Distribution and summary statistics of non-tax output distortions, $\log(1/(1-\tau^W_{fi})) \approx \tau^W_{fi}$, in the USA and the ROW, unweighted.

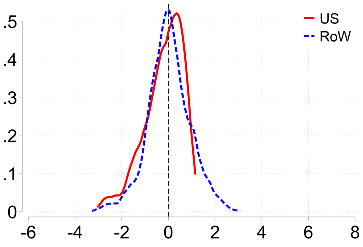


(a) Kernel Density

Region	Mean	Median	Std	p90top10
USA	-0.056	0.000	0.915	2.292
ROW	-0.168	-0.166	0.861	1.845
Diff	0.112	0.166	1.062	1.242

(b) Summary statistics.

Figure 4: Distribution and summary statistics of non-tax capital distortions, $\log(1+\tau^K_{fi}) \approx \tau^K_{fi}$, in the USA and the ROW, unweighted.

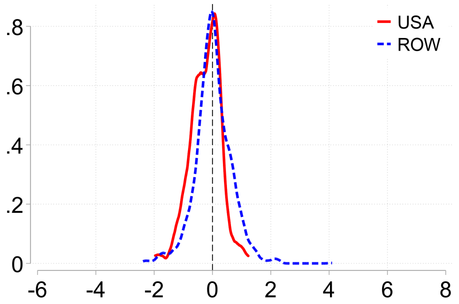


(a) Kernel Density

Region	Mean	Median	Std	p90top10
USA	-0.201	-0.057	0.823	2.062
ROW	0.022	-0.005	0.901	2.193
Diff	-0.223	-0.051	0.914	0.940

(b) Summary statistics.

Figure 5: Distribution of concession productivity $\log(A_{fi})$ in the USA and the ROW - normalized by the average of the (log) of world TFP, unweighted.



(a) Kernel Density

Region	Mean	Median	Std	p90top10
USA	-0.238	-0.175	0.519	1.164
ROW	0.026	0.003	0.624	1.464
Diff	-0.263	-0.178	0.832	0.795

(b) Summary statistics.

Figure 6: Distribution of concession marginal revenue product, $\log(MRP_{fi})$, in the USA and the ROW - normalized by the average of the (log) of world MRPs, unweighted.

or Iran which possess large oil reserves. Interestingly, the quantitative and qualitative pattern in productivity dispersion is very similar to that found in Hsieh and Klenow (2009) - despite our focus on the oil and gas industry and not the manufacturing sector. For example, they find the standard deviation of productivity is 0.79-0.85 for the USA and 0.95-1.23 in China and India.[22] Our data confirms that productivity dispersion is smaller in the USA than in the ROW and is quantitatively similar to theirs: 0.823 for the USA and 0.901 for the ROW.[23]

Finally, Figure 6 shows the (unweighted) distribution and summary statistics for (the log of) the Marginal Revenue Products at each concession - normalized by the average of the (log) of world MRPs.[24]. Like Hsieh and Klenow (2009) we find that marginal revenue products are not equalized *within* regions and that the variation of MRPs is larger outside than within the US. Quantitatively our variation results are similar to theirs - if slightly smaller - even though we only focus on one industry. In particular, Hsieh and Klenow (2009) find the ratio of the 90th to 10th percentiles of TFPR to be 5.0 in India, 4.9 in China, and 3.3 in the United States. As shown in Figure 6, the corresponding values in our data for MRP, are $4.32(\approx e^{1.464})$ in the ROW and $3.2(\approx e^{1.164})$ in the US. In addition, a third fact not directly addressed in Hsieh and Klenow (2009) is that the mean and median marginal revenue products are at a higher *level* in the ROW than within the USA. This is indicative of distortions *between* regions - ROW concessions are implicitly using 'too few' inputs relative to concessions in the USA. We return to this point in our counterfactual exercises.

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[22] Since we only focus on one sector, our results are comparable to their TFPQ or 'physical productivity' measure rather than the TFPR or 'revenue productivity' measure.

[23] Similarly, Hsieh and Klenow (2009) find the p90-p10 ratio of productivity in manufacturing to be 2.05-2.22 in the USA, and 2.44-3.11 in China and India. In our data, the corresponding figures are 2.062 for the USA and 2.193 for the ROW. See Table I in Hsieh and Klenow (2009).

[24] Data is pooled over time and re-normalized for each year. Very similar results hold when looking at specific years in isolation.

5 Results

The Role of Taxation We are interested in quantifying the extent to which the input misallocation defined above can be accounted for by differences in direct revenue-taxation across concessions. Specifically, we are interested in measuring how important revenue tax rates are at explaining cross-concession MRP differences. To do this we will compare the (observed) variation in revenue tax rates to the variation in (model-derived) MRPs. Clearly, this means that we are asking the following question: If all concessions had the same level of non-tax distortions, what would variation in MRP look like in that case, compared to the actual one? To answer this question we perform a classic variance decomposition following Caselli (2005). From (4) and (5) we have:

$$\text{(14)}\quad \text{Var}(\log(MRP_{fi})) = \text{Var}(\log(1-\tau^T_{fi})) + \text{Var}(\log(1-\tau^V_{fi})) + 2\text{Cov}(\log(1-\tau^T_{fi}), \log(1-\tau^V_{fi})),$$

where, $(1-\tau^T_{fi}) \equiv \frac{(1+\tau^K_{fi})^{\frac{\gamma}{\alpha+\gamma}}}{1-\tau^W}$, is a geometric average of all non-tax, implicit distortions at a particular concession. If all concessions had the same level of non-tax wedges we would have $\text{Var}(\log(1-\tau^T_{fi})) = \text{Cov}(\log(1-\tau^T_{fi}), \log(1-\tau^V_{fi})) = 0$. Hence a measure of success of only taxes accounting for observed variation in MRP is:

$$\text{(15)}\quad success_1 = \frac{\text{Var}(\log(1-\tau^V_{fi}))}{\text{Var}(\log(MRP_{fi}))}.$$

The first row of Table 2 shows the above variance decomposition and (in the last column) the success of tax rates in explaining MRP variation in all the world's concessions.[25] We observe that in this decomposition, variation in tax rates account for approximately 57.6% of total variation in MRPs across the world. This is already a sizeable piece of the observed global variation, however as we will argue below, this is likely an under-estimate of the importance of taxation in the variation of MRPs. After correcting for unobserved heterogeneity and model mis-specification, the role of taxation becomes even larger.

The USA as a baseline The accuracy of the above approach hinges on the assumptions of the model itself and the production function in particular as these will influence our measure of non-tax, implicit distortions $(1-\tau^T_{fi})$ and hence our measure of the relative importance of taxation in accounting for variation of MRP. Of course, it is unlikely that the production function in equation (1) and the rest of model perfectly captures the production process in every single concession. True MRPs can vary across concessions due to model mis-specification resulting from (for example) adjustment costs or differences in geography (Restuccia and Rogerson, 2017). We view equation (1) as a rough approximation of the true production process. Our baseline, preferred approach is to accept the fact that the production function is likely to be misspecified

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[25] Throughout this section we are pooling the data and treating our panel as a repeated cross-section. All observations are also weighted by the constant price revenue of the concession.

	(1)	(2) Variance	(3)	(4) Covariance	(5) Success
Region	Total	Wedges	Taxes	Wedges & Taxes	(3)/(1), %
WLD	0.555	0.254	0.320	-0.009	57.6%
ROW	0.540	0.253	0.314	-0.014	58.1%
USA	0.239	0.241	0.019	-0.011	8.0%
ROW-USA	0.301	0.012	0.295	-0.003	98.0%

Table 2: Variance decomposition of the (log) of MRPs for all concessions (WLD), for concessions in the United States (USA) and for concessions in the rest of the world (ROW) following (14). Observations weighted by constant price concession revenue. Final row shows the variance decomposition of the difference in MRPs between the ROW and the USA. Columns refer to: (1) $\mathrm{Var}(\log(MRP_{fi}))$; (2) $\mathrm{Var}(\log(1-\tau^T_{fi}))$; (3) $\mathrm{Var}(\log(1-\tau^V_{fi}))$; (4) $\mathrm{Cov}(\log(1-\tau^T_{fi}), \log(1-\tau^V_{fi}))$.

and that the above measures of success are biased. Instead we argue that it is eminently plausible that misspecification does not systematically differ across two very large regions of the world. In particular, we will use the variation in MRPs of concessions located in the United States as a baseline against which to compare our results. Specifically, we partition the set of locations, $\mathscr{I}$, into regions - those within the United States (USA) and those in the rest of the world (ROW). We denote all concessions belonging to a region, $J \subseteq \mathscr{I}$, by $\bar{J} \equiv \{(f,i) \in \mathscr{F} \times J | c_{fi} = 1\}$. We then compute input-specific MRP according to equations (4) for all concessions in the USA and the ROW and examine their variation in each region. If the differences in the variation of MRPs between concessions located in the USA and the ROW disappear after accounting for taxation, we will be able to infer that variation in measured revenue tax-rates in the ROW is the dominant factor accounting for variation of MRPs. Consequently, our second measure of success of the tax-only model is given by:

$$(16) \quad success_2 = \frac{\mathrm{Var}(\log(1-\tau^V_{fi})_{fi\in\overline{ROW}}) - \mathrm{Var}(\log(1-\tau^V_{fi})_{fi\in\overline{USA}})}{\mathrm{Var}(\log(MRP_{fi})_{fi\in\overline{ROW}}) - \mathrm{Var}(\log(MRP_{fi})_{fi\in\overline{USA}})}.$$

The above measures the extent to which differences in variation in MRPs between the ROW and the USA can be accounted for by differences in the variation in revenue tax-rates between the two regions. If miss-specification does not systematically vary across regions, this measure of success better reflects the role of taxation in accounting for variation in MRPs than our first measure of success.

The second and third row of Table 2 shows the variance decomposition in the ROW and the USA according to (14). Notice that the variation in MRPs is significantly higher in the ROW than the USA. Our goal of course is to understand what accounts for higher variation of distortions in the ROW relative to the USA. Notice that the variation in non-tax distortions in the ROW and the USA shown in column 2, is quantitatively very similar - and statistically indistinguishable. However, variation in tax rates (column 3) is much higher in the ROW than in the USA. As can be see in column (5) variation in taxation accounts for 58.1% of variation in MRPs in the ROW but only

(a) Productivity, $\%\Delta D_J$.

Region	(1) Taxes	(2) Wedges	(3) (1)/(2), %
WLD	24.15%	38.50%	62.7%
ROW	23.18%	37.31%	62.1%
USA	-1.64%	10.56%	-15.5%
ROW-USA	24.82%	26.75%	92.8%

(b) Output, $\%\Delta Y_J$.

Region	(1) Taxes	(2) Wedges	(3) (1)/(2), %
WLD	24.15%	38.50%	62.7%
ROW	29.13%	44.18%	65.9%
USA	-66.41%	-65.44%	101.5%
ROW-USA	95.53%	109.63%	87.1%

Table 3: Productivity (D_J) and Output (Y_J) gains in each region after complete harmonization of: (1) revenue-taxes and (2) all wedges. Column (3) shows proportion of total gains from harmonizing revenue-taxes only. Bottom row shows gains in ROW from harmonizing taxes/wedges to the extent observed in the USA. Values refer to weighted averages for 1980-2013.

8.0% in the USA. The final row of Table 2 shows the importance of the differing variation in tax rates in accounting for the higher rate of variation in MRPs in the ROW. We observe in the final column and row of the table our second measure of success from 16: variation in tax rates alone accounts for approximately 98.0% of the higher variation of MRP observed in the ROW. Thus, the key source of difference in variation in MRPs between the ROW and the USA stems from differences in tax variation.

Counterfactual: We have shown that observed revenue-tax policies account for the large majority of variation in MRPs across concessions. Next, we conduct a simple counterfactual to measure the increase in global productivity (and output) that would occur following a harmonization of *all* distortions and to calculate the proportion of that increase that could be attained by harmonizing tax rates alone.

The first step is to calculate global counterfactual productivity under a policy of perfect tax harmonization. Specifically, we equalize revenue tax-rates across all concessions to some arbitrary but constant level, $\bar{\tau}$,[26] and calculate $\bar{D}_J \equiv D_J|_{\tau^V=\bar{\tau}}$ and $\bar{Y}_J \equiv Y_J|_{\tau^V=\bar{\tau}}$ for $J = WLD$. The results are presented in column 1 of the first row of Table 3(a) and (b). Global productivity gains from harmonization, $100 \times (\frac{\bar{D}_{WLD}}{D_{WLD}} - 1)$, are 24.15%. Since total factors are fixed at a global level, the increase in total output, $100 \times (\frac{\bar{Y}_{WLD}}{Y_{WLD}} - 1)$, is identical to the change in global productivity. Next, we ask how large these gains are relative to a hypothetically fully-efficient economy. We calculate global productivity and output gains after removing *all* distortions from every concession: $D^*_J \equiv D_J|_{\tau^Y=\tau^K=0}$ and $Y^*_J \equiv Y_J|_{\tau^Y=\tau^K=0}$ for $J = WLD$. Like Hsieh and Klenow (2009) we freely acknowledge that this exercise is heroic and makes no allowance for measurement error or model mis-specifcation and that such errors could result in us overstating the efficiency gains from better allocation. However, this measure serves as a useful benchmark against which to compare the relative importance of the tax-harmonization counterfactual. The results are presented in column 2 of the first row of Table 3(a) and (b). Global productivity gains in this

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[26] The specific level of taxation is irrelevant as the term drops out from equation (6): it is difference in taxation that causes misallocation rather than the existence of a tax itself.

case are, $100 \times (\frac{D^*_{WLD}}{D_{WLD}} - 1)$, are 38.50%. As before, since total factors are fixed at a global level, the increase in total output, $100 \times (\frac{Y^*_{WLD}}{Y_{WLD}} - 1)$, is identical. Column 3 of the first row of the above tables then shows that 62.7% - a large majority of gains from moving to a fully efficient world - can be attained only by harmonizing tax rates across concessions. This finding - just like the previous finding pertaining to harmonization of MRPs - emphasizes that variation in tax rates is the leading source of misallocation in the global oil sector.

The above results potentially suffer from the same criticism as before: there can be some level of mis-specification or mis-measurement in our model that could be biasing our findings. Furthermore, it is possible that some variation in tax-rates and distortions may be inevitable and not practicably removable (due to factors such as transportation costs or institutional features) - thus overstating productivity gains. To address these issues we will once more proceed to treat the USA as a baseline and measure global productivity and output gains *relative* to gains in the USA.

We start by repeating the same counterfactuals as in the previous paragraph focusing on our two sub-regions: the USA and the ROW. The results are shown in the second and third rows of Table 3. Eliminating distortions has a very similar effect in ROW as it does globally - resulting in increased productivity, 62.1% of which can be achieved by harmonizing tax-rates alone. Since inputs are not fixed at the regional level, labor and capital can flow between the USA and the ROW in response to changes in relative distortions between regions. Changes in productivity and output at the regional level will thus no longer be the same - as an increase in productivity within a region can be amplified, muted or even reversed by in- or outflows of inputs across regions. In the ROW we observe a higher increase in output than in productivity as workers and capital flow from the USA to the ROW after both counterfactuals. The role of tax-rates is even more important than before as they now account for 65.9% of changes in output if the world moved to eliminate all distortions. The results for the USA deserve further comment. As can be seen from column 2 of the third row of Table 3(a), moving to an efficient world gives rise to an increase in USA productivity of 10.56% - which is smaller than in the ROW. This smaller effect is expected as the variation in distortions in the USA is smaller than in the ROW. Furthermore, from column 2 of the third row of Table 3(b), notice that after full liberalization, output decreases in the USA despite higher productivity. This is because the relative decline in distortions is larger in the ROW than in the USA and inputs move from the USA to the ROW. This indicates that oil production in the USA is 'too high' and sustained by relatively lower distortions. Finally, notice from the first column in Table 3(a) that harmonizing taxes in the USA actually decrease productivity very slightly. This occurs since non-tax wedges are sufficiently negatively correlated with tax distortions that they serve to 'correct' existing non-tax wedges.

Finally, the fourth row of Tables 3(a) and (b) shows the difference between the second and third row. This measures how much higher gains to productivity and output are in the ROW than those in the USA in response to the above counterfactuals. This exercise can be interpreted as measuring productivity and output gains in ROW if either revenue-taxes only or wedges in their entirety were harmonized across concessions - but only to the extent they are in the USA. Moving

	(1)	(2)	(3)	(4)	(5)
		Variance		Covariance	Success
Region	Total	Wedges	Taxes	Wedges & Taxes	(3)/(1), %
WLD	0.476	0.087	0.299	0.045	62.8%
ROW	0.463	0.089	0.290	0.042	62.6%
USA	0.076	0.042	0.023	0.006	29.8%
ROW-USA	0.387	0.047	0.267	0.036	69.0%

Table 4: Variance decomposition of the (log) of MRPs for all concessions (WLD), for concessions in the United States (USA) and for concessions in the rest of the world (ROW) with *heterogeneous elasticities*. Observations weighted by constant price concession revenue. Final row shows the variance decomposition of the difference in MRPs between the ROW and the USA. Columns refer to: (1) $\text{Var}(\log(MRP_{fi}))$; (2) $\text{Var}(\log(1-\tau^T_{fi}))$; (3) $\text{Var}(\log(1-\tau^V_{fi}))$; (4) $\text{Cov}(\log(1-\tau^T_{fi}), \log(1-\tau^V_{fi}))$.

to 'US-taxation' would result in productivity gains in the ROW of 24.82% and output gains of 95.53% whereas moving to 'US-efficiency' would result in productivity gains in ROW of 26.75% and output gains of 109.63%. A policy change that harmonized taxes in the ROW to the same extent as they are in the USA, would thus achieve 92.8% of total gains in productivity and 87.1% of total gains in output that could be achieved from moving to 'US-Efficiency' in the ROW. We can thus see that almost all the misallocation observed in the oil sector in the ROW above and beyond that in the USA is due to greater dispersion in tax rates across concessions in the ROW.

6 Heterogenous Elasticities

So far we have assumed that each concession has the same labor and capital elasticity both in order to remain close to the literature and for simplicity. Of course it is quite plausible that elasticities vary across concessions, or at the very least across countries.[27] This may mean that non-tax wedges estimated above might be capturing variation in factors such as geology rather than distortions - thus under-estimating the role of taxation. In other words, accounting for heterogeneity in elasticities might reduce variation in MRPs and imply an even greater role for taxation in accounting for variation in MRPs across concessions.

In our baseline we argued that by examining differences in MRPs between regions (i.e. between the ROW and the USA) rather than looking at specific regions in isolation this assumption would not largely bias our result. To the extent that the true distribution of elasticities is similar in the USA and the ROW, the bias in after non-tax wedges should not be systematically different across the two regions. In what follows we suggest an alternative way of addressing this issue. Whilst in our baseline we pooled our panel data into a repeated cross-section, here instead we exploit the variation of MRPs over time to show that also along this dimension variation in MRPs is overwhelmingly driven by variation in revenue tax rates.

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[27] Geologically difficult concessions - such as deep-sea concessions in the Gulf od Mexico or the Tar Sands in Alaska may be, for example, have a higher capital elasticity than Saudi Arabian surface concessions.

	(1)	(2)	(3)
Region	Taxes	Wedges	(1)/(2), %
WLD	18.97%	23.09%	82.1%
ROW	24.22%	28.72%	84.3%
USA	-62.54%	-65.71%	95.2%
ROW-USA	86.76%	94.42%	91.9%

Table 5: Output (Y_J) gains globally and in each region after complete harmonization of: (1) revenue-taxes and (2) all wedges in the case of *heterogenous elasticities*. Column (3) shows proportion of total gains from harmonizing revenue-taxes only. Bottom row shows gains in ROW from harmonizing taxes/wedges to the extent observed in the USA. Values refer to weighted averages for 1980-2013.

We proceed by estimating concession-specific elasticities by assuming that the median non-tax wedge of a concession - denoted by $(\bar{\bar{\cdot}})$ - is zero over time. In particular, we now affix a time subscript to each variable of our model and, letting T_{fi} be the set of years a particular concession appears in our data, we assume for each $(f,i) \in \bar{\mathscr{I}}$ that $\overline{\overline{(\tau^K_{fi,t})}}_{t \in T_{fi}} = \overline{\overline{(\tau^W_{fi,t})}}_{t \in T_{fi}} = 0$. In other words, that median non-tax wedges at each concession are zero over time. Then, using this assumption and (4), we obtain:

$$(17) \quad \alpha_{fi} = \overline{\overline{\left(\frac{w_t L_{fi,t}}{(1-\tau^V_{fi,t}) P_t Y_{fi,t}} \right)}}_{t \in T_{fi}} \quad \text{and} \quad \frac{\alpha_{fi}}{\gamma_{fi}} = \overline{\overline{\left(\frac{w_t L_{fi,t}}{r_t K_{fi,t}} \right)}}_{t \in T_{fi}},$$

which can be used to determine α_{fi} and γ_{fi} for each concession $(f,i) \in \bar{\mathscr{I}}$. The above calibration is based on the implicit assumption that over long periods of time, non-tax distortions at a concession simply do not play a large role so that concessions are efficient and their elasticities reflect differences in environment and geology. Deviations from measured efficiency in the short run however can occur and reflect temporary bottlenecks, constraints or other distortionary factors.

Given the above, we can extract wedges and concession productivities exactly as before using equations (11)-(13). Then, using (14) we perform the same variance decomposition as before to quantify the extent to which variation in MRPs can be accounted for by variation in direct revenue-taxation across concessions. The results for the heterogeneous elasticity case are shown in Table 4. As expected, the variance of non-tax wedges in column (2) is now significantly reduced from before and is 0.087. This is because a part of the variation in MRPs that previously was interpreted as distortions is now captured by variation in elasticities and hence production functions across concessions. This mechanically results in (the unchanged) taxes accounting for a greater part of the variation than before: 62.8% globally.[28] Interestingly, the fourth row of the table lends support to our original argument that adopting the USA as a baseline is a good way of capturing un-modelled heterogeneity. The difference in variation in MRPs and non-tax wedges

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[28] The variation in taxes in Table 4 is slightly different from the variation in taxes in Table 4 as we now drop the observations where our calibration implies that $\alpha_{fi} + \gamma_{fi} > 1$.

	(1)	(2)	(3)	(4)
		Tax harmonization		
	All	Within Firm	Across Firm	All Wedges
Productivity Gains	24.15%	-1.20%	24.56%	38.50%
Relative to Full Efficiency	62.7%	-3.1%	63.8%	100%

Table 6: The first row shows global productivity (B_J) gains after: (1) complete harmonization of revenue-taxes (2) within firm harmonization of tax-rates only (3) across firm harmonization of tax-rates only (4) elimination of all tax and non-tax distortions. The second row shows the gains of each counterfactuals relative to gains from eliminating all tax and non-tax distortions (i.e. full efficiency). Values refer to weighted averages for 1980-2013.

between the ROW and the USA and hence the relative importance of taxation in accounting for this difference remain relatively close to our baseline estimates in Table 2.

Finally, Table 5 performs the same counterfactual as before and calculates that we could reach 82.1% of the global efficient output if a harmonization of tax rates across concessions took place. Thus tax-harmonization in this case would bring us almost as close to full efficiency as in the baseline case. However, looking once more at the difference between the ROW and the USA, we find the results largely unchanged relative to the baseline.[29] Thus, although accounting for elasticity heterogeneity mechanically increases the relative importance of taxes, the above suggests that our preferred baseline approach which examines *differences* in variations of MRPs across regions but keep the same production function across all concessions, is robust enough to take into account potentially missing features from the original model that do not systematically vary across regions.

7 Sources of misallocation

Inter- versus intra-firm tax differences Our data contains many multi-national firms that have multiple concessions around the world as well as firms that have concessions only in a single country. We make use of this fact and investigate whether observed misallocation arises from tax-rates varying *within* firms - that is, across a firm's different concession holdings - or rather whether it is a consequence of a variation in tax rates *across* different firms.

To answer this, we make use of our model. In particular we estimate global productivity gains from two counterfactuals: 1) First, we harmonize tax-rates across all concessions belonging to the same firm - by setting a firm (and year) specific tax-rate equal to the average of the tax-rates currently faced by the firm; 2) Second, we harmonize average tax rates across firms (and years) but allow within firm variation of taxes to remain at its current levels.[30] The results are shown in Table 6. The first three columns show the global productivity gains from harmonizing: (1) all taxes, (2)

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[29] Notice that we do not include productivity results in Table 5 as no closed form solution for regional productivity exists with heterogenous elasticities. It thus makes more sense to look at output rather than productivity.

[30] Specifically, we first define $\bar{f}$ as the set of all concessions belonging to firm f, $\bar{f} \equiv \{(f,i) \in f \times \mathscr{I} | c_{fi} = 1\}$.

	(1)	(2) Variance	(3)	(4) Covariance	(5) Success
Region	Total	Wedges	Taxes	Wedges & Taxes	(3)/(1), %
WLD	0.555	0.254	0.320	-0.009	57.6%
Public	0.509	0.263	0.306	-0.029	60.0%
Private	0.387	0.208	0.201	-0.011	51.8%
OPEC	0.308	0.264	0.219	-0.087	71.1%
Non-OPEC	0.301	0.202	0.143	-0.022	47.6%

Table 7: Variance decomposition of the (log) of MRPs for all concessions (WLD), as well as for concessions held by public and private companies and for concessions located within and outside of OPEC countries following (14). Observations weighted by output. Columns refer to: (1) $\mathrm{Var}(\log(MRP_{fi}))$; (2) $\mathrm{Var}(\log(1-\tau^T_{fi}))$; (3) $\mathrm{Var}(\log(1-\tau^V_{fi}))$; (4) $\mathrm{Cov}(\log(1-\tau^T_{fi}), \log(1-\tau^V_{fi}))$.

taxes within firms only and (3) taxes across firms only. In the second row these gains are expressed relative to total gains from eliminating all distortions. As can be seen harmonizing tax rates across firms results in nearly identical gains as harmonizing all taxes, whereas harmonizing tax rates only within firms results in a very slight decrease in productivity. This suggests that differing tax treatment of firms across the world is a key source of distortions in the oil industry rather than differing tax-treatments of specific concessions - even across countries. Interestingly, this is true despite individual firms operating concessions around the world and in different countries. This perhaps suggests that companies with multiple concessions throughout the world may have higher clout when negotiating tax-concessions with governments than smaller companies operating only in individual countries.

Other influences Our final exercise examines the importance of taxation in accounting for variation in MRP in different sub-samples of the data. This can be a useful exercise as it highlights the cases where tax-driven wedges and non-tax wedges play different roles.

First, we examine the difference in the decomposition between concessions held by public and private firms as well as concessions operating within and outside of OPEC countries. The results are presented in Table 7. Revenue taxes are especially important in accounting for variation in MRPs in OPEC countries as well as among state owned (or public) companies. Notice also that variation in non-tax wedges is higher in both OPEC and state owned firms than in non-OPEC and private firms respectively - capturing the fact that these groups of concessions face important non-tax wedges to MRPs in addition to tax-driven distortions that contribute to misallocation.

Next, we examine the role played by age, size and productivity of individual concessions. In

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Then, in the first counterfactual, we set tax-rates at each concession, $\widetilde{\tau^V_{fi}}$, equal to the firms average tax rates across all its concessions, $\widetilde{\tau^V_{fi}} \equiv \overline{\left(\tau^V_{fi}\right)}_{fi\in\bar{f}}$. In the second counterfactual, we set tax-rates at each concession, $\widetilde{\widetilde{\tau^V_{fi}}}$, equal to the difference between the observed tax rate at the concession and the average firm-level tax rate: $\widetilde{\widetilde{\tau^V_{fi}}} \equiv \tau^V_{fi} - \widetilde{\tau^V_{fi}}$.

	(1)	(2)	(3)	(4)	(5)
		Variance		Covariance	Success
Region	Total	Wedges	Taxes	Wedges & Taxes	(3)/(1), %
WLD	0.555	0.254	0.320	-0.009	57.6%
Oldest	0.597	0.245	0.328	0.012	55.0%
Youngest	0.510	0.189	0.374	-0.027	73.4%
Largest	0.537	0.248	0.318	-0.015	59.3%
Smallest	0.445	0.443	0.128	-0.063	28.8%
Most Productive	0.428	0.216	0.309	-0.048	72.1%
Least Productive	0.212	0.242	0.117	-0.073	55.1%

Table 8: Variance decomposition of the (log) of MRPs for all concessions (WLD), for concessions held by private companies (PRV) and for concessions held by public companies (PUB) following (14). Final row shows the variance decomposition of the difference in MRPs between PUB and PRV concessions. Columns refer to: (1) $\text{Var}(\log(MRP_{fi}))$; (2) $\text{Var}(\log(1-\tau^{T}_{fi}))$; (3) $\text{Var}(\log(1-\tau^{V}_{fi}))$; (4) $\text{Cov}(\log(1-\tau^{T}_{fi}), \log(1-\tau^{V}_{fi}))$.

particular we look at the top and bottom quartiles of concessions according to their age (years since first appearing in our data), size (total revenues in constant, 2010 US$) and their productivity (A_{fi} calculated in 13 above). The results are shown in Table 8. Notice that variation in tax-rates plays an important role in accounting for overall dispersion in MRP in all the above cases. This is especially true in the youngest and most productive concessions where variation in tax rates accounts for 73.4% and 72.1% of total variation in MRPs respectively. Taxation plays the least important role among the smallest concessions where other non-tax wedges are more important sources of distortions. This makes sense in that smaller concessions may face higher frictions such as borrowing constraints in comparison to larger concessions.

8 Conclusion

We have examined the role that variation in revenue tax rates play in misallocation and productivity in the upstream oil and gas industry. We have shown that a very large proportion of variation in MRPs globally is accounted for by variation in revenue tax rates. Furthermore, practically all of the additional variation in MRPs observed in countries outside the USA relative to the variation observed in the USA is driven by a higher dispersion of tax rates. To the extent that the results are generalizable to other industries, this strongly suggests that a large part of observed misallocation - and importantly productivity differences - may arise from a lack of harmonization of tax rates. Harmonizing tax rates globally to the extent observed in the USA, would increase global productivity in the sector by a massive 25% - or nearly 93% of the gains that we would obtain if inputs around the world were allocated as efficiently as they were in the United States. Policy makers interested in increasing productivity in the oil sector would do well to take note of these results. Researchers should also find the results interesting as they highlight a case when distortions stemming from a directly observable source account for almost all the misallocation as measured via indirect, model-based methods - something that to our knowledge has not been documented before.

Future research calls for a greater disaggregation of the data along two dimensions. First, geographically, our data from Wood Mackenzie is at the region- or country-concession level, whereas data from both Wood Mackenzie and Rystad Energy are in principle (but at great cost) available at the field or well level. Obtaining data at that level of disaggregation would be helpful to determine exactly where (geographically speaking) tax distortions really bite - and to see the role that tax variation plays at a sub-national level. Second, more detailed proprietary data also exists for our Total Government Take measure. Obtaining such dissagregated data would enable us to disentangle the influence of specific types of taxes on misallocation and narrow in on the sources of variation of MRPs even more.

Finally, perhaps the most exciting avenue of future research, would be to obtain tax data from other economic sectors in order to investigate how generalizable our results really are. Quantitatively, both the extent of variation in MRPs in and outside the USA are similar in the oil and gas sector to those found in the manufacturing sector in other studies. Dispersion in productivity in our sector also seems to be similar to that of in the manufacturing sector. These observations hint - at least somewhat - at the generalizability of our results to other sectors. If true, this in turn would suggest that tax policy could play a massive and crucial role in accounting for dispersion in MRPs across firms and in hence in observed differences in productivity and output per worker across countries.

9 Appendix

Construction of Capital Stock Here we discuss the construction of capital stock used in the main body of the paper. We largely follow Caselli (2005) and Kuralbayeva and Stefanski (2013). First, we use the US GDP price index from the Penn World Tables (Heston et al., 2012) to deflate capital expenditure data, $\widetilde{I}_{fi,t}$, and write it in terms of constant 2010 US\$, which we denote by $I_{fi,t}$. Next we use the perpetual inventory equation to derive the capital stock at each concession:

$$K_{fi,t+1} = (1-\delta)K_{fi,t} + I_{fi,t}, \tag{18}$$

where $K_{fi,t}$ is the capital stock of firm f at concession i at time t and δ is the depreciation rate of capital stock. In a standard fashion we guess the initial capital stock $K_{fi,0}$ as $I_{fi,0}/(g_{fi}+\delta)$, where $I_{fi,0}$ is the value of the above investment series in the first period that it is available, and g_{fi} is the long run (gross) growth rate of $I_{fi,t}$ for the firm-concession pair fi. We use three different measures of this growth rate: 1) the slope in the regression of log of $I_{fi,t}$ on time; 2) average geometric growth rate of $I_{fi,t}$ over the first 10 years the data is available for each concession; and 3) the average geometric growth rate of $I_{fi,t}$ over the first 10 years for US concessions only (which is 3.79%). We then choose between the three initial capital stock guesses by adopting the first capital stock measure that does not imply a negative initial capital stock. As is discussed in the literature - and by Caselli (2005) - the choice for initial capital stock is tenuous and stems from the assumption that an economy or a sector is on a balanced growth path of a Solow-type model (with a trend growth rate of g_{fi}) in the initial year. Importantly, over time the guess of the initial capital stock becomes irrelevant as investment flows accumulate and dominate the initial guess. To ensure that the choice of the initial capital does not drive our results, we drop the first ten years of capital stock estimates for each concession. Finally, we set the depreciation rate, δ, to 0.0736 which we obtain as the average Implied Depreciation Rate for Private Nonresidential Fixed Assets of the Oil and Gas sector between 1976 and 2013 from the BEA (2020). Our capital stock measures prove not to be very sensitive to choices in either δ, g_{fi} or initial capital stock. The above process gives us sequences of capital stocks used in the main body of the paper.

Dynamic Problem Notice that we can write the static firms problems in a dynamic form:

$$\max_{\{K_{fi,t+1},L_{fi,t},I_t\}_{t=0}^{\infty}} \sum_{i\in\mathscr{I}_f} \sum_{t=0}^{\infty} \left(\prod_{k=1}^{t} \frac{1}{1+R_k} \right) \left(p_t(1-\tau^Y_{fi,t})Y_{fi,t} - w_t L_{fi,t} - I_t - \tau^K_{fi,t}(R_t+\delta)K_{fi,t} \right) \tag{19}$$

$$\text{s.t. } K_{fi,t+1} = (1-\delta)K_{fi,t} + I_t.$$

In the above, firms can accumulate capital and their purpose is to maximize the net-present value of cash-flow. Notice that the discount rate for firms is a function of the real interest rate, R_t. In addition, all prices are normalized with respect to the price of investment. Finally, notice that $\tau^K_{fi,t}$ is simply a distortion on the cost of capital utilization. The first order conditions of the above problem are the same as those of the static firm profit-maximization in the main body of the paper.

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